# Index Site Surveys for Olympia Oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2009 to 2017

T.C. Norgard, M.I. Bigg, S.E.M. MacConnachie, J.L. Finney and G.E. Gillespie

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

2018

**Canadian Technical Report of Fisheries and Aquatic Sciences 3153**

Canadian Technical Report of Fisheries

and Aquatic Sciences 3153

2018

# INDEX SITE SURVEYS FOR OLYMPIA OYSTERS (*OSTREA LURIDA* CARPENTER, 1864) IN BRITISH COLUMBIA – 2009 to 2017

by

T.C. Norgard, M.I. Bigg, S.E.M. MacConnachie, J.L. Finney and G.E. Gillespie

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, British Columbia V9T 6N7

© Her Majesty the Queen in Right of Canada, 2018.
Cat. Fs97-4/3153E-PDF ISBN 978-0-660-25248-3 ISSN 1488-5387

Correct citation for this publication:

T.C. Norgard, M.I. Bigg, S.E.M. MacConnachie, J.L. Finney and G.E.Gillespie. 2018. Index site surveys for Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2009 to 2017. Can. Tech. Rep. Fish. Aquat. Sci. 3153: viii + 88 p.

# Table of Contents


**LIST OF TABLES** ..... **IV**

**LIST OF FIGURES** ..... **IV**

**LIST OF APPENDICES** ..... **VI**

**ABSTRACT** ..... **VII**

**RÉSUMÉ** ..... **VIII**

**INTRODUCTION** ..... **1**

**METHODS** ..... **1**

**RESULTS AND DISCUSSION** ..... **5**

NORTHWEST VANCOUVER ISLAND ..... 5

*Klaskino Inlet* ..... *5*

*Amai Inlet* ..... *6*

*Port Eliza Beach 3* ..... *7*

SOUTHWEST VANCOUVER ISLAND ..... 8

*Darr Island* ..... *9*

*Bacchante Bay* ..... *9*

*Harris Point* ..... *10*

*Hillier Island* ..... *11*

*Joes Bay* ..... *12*

JUAN DE FUCA STRAIT ..... 13

*Gorge Site 9* ..... *13*

*Ayum Creek* ..... *14*

STRAIT OF GEORGIA ..... 15

*Jervis Inlet 1* ..... *15*

*Baker Bay* ..... *16*

*Swy-a-Lana Lagoon* ..... *17*

*Transfer Beach* ..... *18*

**CONCLUSIONS** ..... **18**

**ACKNOWLEDGEMENTS** ..... **19**

**REFERENCES** ..... **20**

**APPENDICES** ..... **62**

# List of Tables


TABLE 1. SURVEY DATES FOR OLYMPIA OYSTER INDEX SITES, 2009-2017. ..... 22
TABLE 2. CALCULATED OYSTER BED AREA ($M^2$) FROM GPS SURVEY, TOTAL AREA SURVEYED ($M^2$) AND PERCENTAGE OF THE BED AREA SURVEYED FOR OLYMPIA OYSTER INDEX SITES. ..... 23
TABLE 3. SURVEY DESIGN, DENSITY AND 95% CIS FOR ALL SIZE CLASSES OF OLYMPIA OYSTERS AT INDEX SITES IN NORTHWEST VANCOUVER ISLAND 2010-2017. ..... 24
TABLE 4. SURVEY DESIGN, DENSITY AND 95% CIS FOR SMALL SIZE CLASS (≤ 15 MM) OF OYSTERS AT INDEX SITES IN NORTHWEST VANCOUVER ISLAND 2010-2017. ..... 25
TABLE 5. MEAN, VARIABILITY AND RANGE OF OLYMPIA OYSTER SHELL LENGTH (MM) AT INDEX SITES IN BRITISH COLUMBIA, 2009-2017. ..... 26
TABLE 6. SURVEY DESIGN, DENSITY AND 95% CIS FOR ALL SIZE CLASSES OF OLYMPIA OYSTERS AT INDEX SITES IN SOUTHWEST VANCOUVER ISLAND 2010-2017. ..... 27
TABLE 7. SURVEY DESIGN, DENSITY AND 95% CIS FOR SMALL SIZE CLASS (≤ 15 MM) OF OYSTERS AT INDEX SITES IN SOUTHWEST VANCOUVER ISLAND 2010-2017. ..... 28
TABLE 8. SURVEY DESIGN, DENSITY AND 95% CIS FOR ALL SIZE CLASSES OF OLYMPIA OYSTERS AT INDEX SITES IN JUAN DE FUCA STRAIT 2009-2016. ..... 29
TABLE 9. SURVEY DESIGN, DENSITY AND 95% CIS FOR SMALL SIZE CLASS (≤ 15 MM) OF OYSTERS AT INDEX SITES IN JUAN DE FUCA STRAIT 2009-2016. ..... 30
TABLE 10. SURVEY DESIGN, DENSITY AND 95% CIS FOR ALL SIZE CLASSES OF OLYMPIA OYSTERS AT INDEX SITES IN THE STRAIT OF GEORGIA 2010-2016. ..... 31
TABLE 11. SURVEY DESIGN, DENSITY AND 95% CIS FOR SMALL SIZE CLASS (≤ 15 MM) OF OYSTERS AT INDEX SITES IN THE STRAIT OF GEORGIA 2010-2016. ..... 32


# LIST OF FIGURES


FIGURE 1. OLYMPIA OYSTER INDEX SITES SURVEYED IN BRITISH COLUMBIA, 2009-2017. 33
FIGURE 2. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN KLASKINO INLET. ..... 34
FIGURE 3. A) KLASKINO INLET OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) KLASKINO INLET OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 35
FIGURE 4. LOCATION AND STRATUM LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN AMAI INLET. ..... 36
FIGURE 5. A) AMAI INLET OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) AMAI INLET OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 37
FIGURE 6. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE AT PORT ELIZA BEACH 3. ..... 38

# List of Figures (cont.)

FIGURE 7. A) PORT ELIZA BEACH #3 OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) PORT ELIZA BEACH 3 OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 39
FIGURE 8. LOCATION AND STRATUM LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN DARR ISLAND. ..... 40
FIGURE 9. A) DARR ISLAND OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) DARR ISLAND OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 41
FIGURE 10. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN BACCHANTE BAY. ..... 42
FIGURE 11. A) BACCHANTE BAY OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) BACCHANTE BAY OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 43
FIGURE 12. LOCATION AND STRATUM LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE AT HARRIS POINT. ..... 44
FIGURE 13. A) HARRIS POINT OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B). HARRIS POINT OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 45
FIGURE 14. LOCATION AND STRATUM LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE AT HILLIER ISLAND. ..... 46
FIGURE 15. A) HILLIER ISLAND OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) HILLIER ISLAND OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 47
FIGURE 16. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN JOES BAY. ..... 48
FIGURE 17. A) JOES BAY OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM). B) JOES BAY OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 49
FIGURE 18. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE AT GORGE SITE 9. ..... 50
FIGURE 19. A) GORGE WATERWAY OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) GORGE WATERWAY OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 51
FIGURE 20. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE AT AYUM CREEK. ..... 52

# List of Figures (cont.)

FIGURE 21. A) AYUM CREEK OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) AYUM CREEK OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 53
FIGURE 22. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN JERVIS INLET. ..... 54
FIGURE 23. A) JERVIS INLET OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) JERVIS INLET OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 55
FIGURE 24. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN BAKER BAY. ..... 56
FIGURE 25. A) BAKER BAY OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) BAKER BAY OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 57
FIGURE 26. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE IN SWY-A-LANA LAGOON. ..... 58
FIGURE 27. A) SWY-A-LANA LAGOON OLYMPIA OYSTER DENSITY(# $M^{-2}$) BY STRATUM AND YEAR . THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) SWY-A-LANA LAGOON OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 59
FIGURE 28. LOCATION AND STRATA LAYOUT FOR THE OLYMPIA OYSTER INDEX SITE AT TRANSFER BEACH. ..... 60
FIGURE 29. A) TRANSFER BEACH OLYMPIA OYSTER DENSITY (# $M^{-2}$) BY STRATUM AND YEAR. THE *ALL SIZES* CATEGORY INCLUDES THE *SMALL* SIZE CATEGORY. THE *SMALL* SIZE CATEGORY INCLUDES OYSTERS ≤ 15 MM. B) TRANSFER BEACH OLYMPIA OYSTER SIZE FREQUENCY (MM). RED DOTTED LINES ARE MEAN LENGTH (MM). ..... 61

# List of Appendices

APPENDIX 1. R CODE USED FOR SETTING TWO-STAGE SURVEY DESIGNS. ..... 62
APPENDIX 2. R CODE USED FOR CALCULATING DENSITY OF OLYMPIA OYSTERS AT EACH SITE IN 3 DIFFERENT SIZE CATEGORY FORMATS ("ONLY SMALL OYSTERS (≤15MM)", "LARGE (>15MM) AND SMALL OYSTERS (≤15MM)", AND "LARGE OYSTERS (>15MM) ONLY"). ..... 82
APPENDIX 3. R CODE FOR OLYMPIA OYSTER DENSITY GRAPHS ..... 86

# Abstract

T.C. Norgard, M.I. Bigg, S.E.M. MacConnachie, J.L. Finney and G.E.Gillespie. 2018. Index site surveys for Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2009 to 2017. Can. Tech. Rep. Fish. Aquat. Sci. 3153: viii + 89 p.

The Olympia oyster (*Ostrea lurida* Carpenter, 1864) was designated a species of Special Concern under the Canadian Species at Risk Act in 2003. A management plan was developed in 2009, and a primary objective was maintenance of relative abundance (density) at index sites. Fourteen index sites were chosen to monitor density within their range in Canadian waters. Sites have been surveyed at least twice since 2009. Density, length frequency, and bed area have been determined for sites. Densities varied across sites and years, and ranged from $507 \pm 74.1$ $m^{-2}$ at Port Eliza in 2013 to $0.6 \pm 0.4$ at Bacchante Bay in 2012. The time series at most sites is short and precluded evaluation of trends. However, baseline information from index site data and continued monitoring will enable future analysis of variability and trends.

# Résumé

T.C. Norgard, M.I. Bigg, S.E.M. MacConnachie, J.L. Finney and G.E. Gillespie. 2017. Index site surveys for Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2009 to 2017. Can. Tech. Rep. Fish. Aquat. Sci. 3153: viii + 88 p.

En 2003, l'huître indigène du Pacifique (*Ostrea lurida* Carpenter, 1864) a été désignée comme espèce préoccupante en vertu de la *Loi sur les espèces en péril* du Canada. Un plan de gestion a été élaboré en 2009, et l'un des principaux objectifs de ce plan consistait à maintenir l'abondance relative (densité) de l'espèce à des sites repères. Quatorze sites repères ont été choisis pour surveiller la densité de l'espèce dans son aire de répartition dans les eaux canadiennes. Ces sites ont fait l'objet de relevés au moins deux fois depuis 2009. Des mesures relatives à la densité, à la fréquence de longueur et à la superficie du gisement ont été prises à chacun des sites. Les densités variaient d'un site à l'autre et d'une année à l'autre, de 507 ± 74.1 $m^{-2}$ à Port Eliza en 2013 à 0,6 ± 0,4 $m^{-2}$ à la baie Bacchante en 2012. Puisque la série chronologique de relevés à la plupart des sites était courte, elle n'a pas permis l'évaluation des tendances. Toutefois, les renseignements de base prélevés aux sites repères ainsi qu'une surveillance continue permettront l'analyse future de la variabilité des tendances.

# Introduction

The Olympia oyster, *Ostrea lurida* Carpenter, 1864 (= *Ostrea conchaphila* Carpenter, 1857 [*partim*]), is one of four species of oysters established in British Columbia (BC), Canada, and the only naturally occurring oyster in BC (Bourne 1997; Gillespie 1999, 2009). *O. lurida* reaches the northern limit of its range in the Central Coast of BC at Gale Passage, Campbell Island, approximately 52°12'N, 128°24'W (Gillespie 2009).

First Nations historically utilized Olympia oysters for food and their shells for ornamentation (e.g., Ellis and Swan 1981; Harbo 1997). European settlers harvested Olympia oysters commercially from the early 1800s until the early 1930s when stocks became depleted and the industry moved towards other larger, introduced oyster species (Bourne 1997; Quayle 1988). Since that time, Olympia oysters have likely maintained stable populations in BC, but have not recovered to abundance levels observed prior to the late 1800s (Gillespie 1999, 2009).

Olympia oysters were designated a species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2000 and 2010 and listed under the Species at Risk Act (SARA) in 2003 (DFO 2009; COSEWIC 2011). A management plan was developed and posted to the SARA Public Registry in 2009 (DFO 2009). One of the objectives of this plan was to ensure maintenance of the relative abundance (density) of Olympia oyster at index sites. The plan also recommended development of a survey protocol for determining density estimates. In response, a Canadian Science Advisory Secretariat (CSAS) Research Document was completed recommending a survey method for Olympia oysters (Norgard et al. 2010); a CSAS Science Advisory Report (DFO 2010) for selection of index sites was also completed.

Thirteen index sites were chosen from a mixture of previously surveyed sites, and by random site selection. In 2014, a fourteenth site was added at Joes Bay in the Broken Group area in partnership with Parks Canada. The selected sites provided a representative sample of Olympia oyster populations in different geographic zones in the Pacific region and span the much of the range of Olympia oysters in BC (Figure 1).

This report summarizes results from 43 surveys at 14 index sites from 2009 to 2017.

# Methods

During initial site investigations (2009-2011), oyster beds were identified from literature (e.g., Gillespie 2009; Stanton et al. 2011; Finney et al. 2012) and through reconnaissance to determine beaches that had Olympia oysters present. The rationale for index site selection followed DFO (2010).

Defining and Mapping Survey Strata and Oyster Beds

Survey strata were positioned to cover as much of the oyster bed as possible while maximizing the area to be surveyed in one tide. Survey strata were rectangular in shape to allow for ease of survey set-up. Stratification was used at 10 index sites where beds were large or discontinuous. The remaining index sites had one stratum. Refinements to stratum boundaries have been made since 2009 to exclude areas that are not able to be surveyed (e.g., subtidal portions) and slight increases to stratum area have occurred to included more habitat if time allowed.

Coordinates of all Olympia oyster beds, strata and corner points were collected each survey year using Trimble GPS Pathfinder Pro. Mapping of Olympia oyster beds was focused on survey stratum when time did not permit mapping of the entire beach. The outer boundaries of the beds were defined by the absence of oysters. Strata coordinates from prior survey years were used to locate index sites.

Survey Design

All 43 surveys followed either two-stage (TS) or stratified two-stage (StTS) survey design (*fide* Gillespie and Kronlund 1999; Norgard et al. 2010); the rationale and methodology for use of two-stage designs for Olympia oyster index surveys was described in Norgard et al. (2010) . Transect and quadrat positions were chosen in advance of surveys using R software code (Appendix 1).

In this design the first stage units were established by placing a tape measure on the beach substrate to form a baseline along the length of the stratum. First stage units or transects were then randomly selected at positions along the baseline. The transect length was then divided by the number of desired quadrats and the first quadrat on these perpendicular transects randomly selected in the first portion of the transect. The remaining quadrats were then systematically positioned along the length of transect. Corner points of each stratum and quadrat were marked with flags.

Sampling Intensity

Sampling intensity (number of quadrats) surveyed in each stratum was determined at the time of survey and was dependent on the amount of time available to complete the survey and the density of Olympia oysters at the site. A sampling intensity of 50 quadrats was targeted for high density beaches and 100 quadrats for low density beaches as per Norgard et al. (2010). Refinements to sampling intensity have been made at numerous sites to address the objectives of narrowing confidence intervals (CIs) and improving survey precision (defined below).

Data Collection

Sites were surveyed at the lowest spring and summer tide cycles. Surveys utilized quadrats of area 0.25 $m^2$ (50 cm x 50 cm) as recommended in Norgard et al. (2010) with

the exception of 2011, when four beaches were surveyed with quadrats covering 0.0625 $m^2$ (25 cm x 25 cm) in area. The number of live Olympia oysters located on the surface layer of the quadrat including on rocks, shells and other substrate was counted and recorded in field notebooks.

Olympia oyster shell lengths were measured and collated to understand potential trends in growth and recruitment. Quadrats were randomly selected to conduct shell measurement. All oysters within the quadrats were measured until a minimum sample size of 50 oysters was attained. Shell length was measured by bisecting the shell vertically from the umbo to the posterior shell margin (Quayle 1988). The number of oysters measured varied considerably between years and sites. Sample size was dependent on the amount of time available to complete all survey elements; if time permitted, more were measured.

Prior to 2011, Olympia oysters were not separated into size categories and the densities for those years included all sizes of oysters. A small size category (shell length $\leq$ 15 mm) was created to allow densities of small oysters to be presented separately. For beaches with both Olympia and Pacific oysters, the small size category acknowledges the level of uncertainty inherent in distinguishing small oysters of the two species. This category has the potential of documenting recruitment events like those evident at Port Eliza Beach 3 and Hillier Island where hundreds of small oysters were counted.

All data collected were entered into DFOs intertidal database managed by the Fishery and Assessment Data Unit at the Pacific Biological Station, Nanaimo BC.

# Analysis

The Independent Sampling Design function (Svydesign) from the R software package was used to calculate density (Appendix 2). The Svydesign is a robust method to calculate density that can adjust for different lengths of transects within the two stage sampling design using a cluster analysis. Data in all surveys were standardized to 1 $m^2$ within the R code as part of the analysis. R software code was also used to produce all density graphs (Appendix 3).

For surveys with more than a single stratum, overall density estimates were calculated using the methods of Gillespie and Kronlund (1999). The population mean was estimated as:

$$\bar{y}_{sts} = \frac{\sum_{h=1}^{H} N_h M_h \bar{y}_h}{\sum_{h=1}^{H} N_h M_h} = \sum_{h=1}^{H} W_h \bar{y}_h$$

where

$$W_h = \frac{N_h M_h}{\sum_{h=1}^{H} N_h M_h}$$

and

$$\bar{y}_h = \frac{1}{n_h m_h} \sum_{i=1}^{n_h} \sum_{j=1}^{m_h} y_{hij} .$$

The variance of the population mean was estimated as:

$$\hat{V}(\bar{y}_{STS}) = \sum_{h=1}^{H} W_h^2 \left[ \frac{1 - n_h / N_h}{n_h} s_{1h}^2 + \frac{\left(n_h / N_h\right)\left(1 - m_h / M_h\right)}{n_h m} s_{2h}^2 \right]$$

where

$$s_{1h}^2 = \frac{\sum_{i=1}^{n_h} (\bar{y}_{hi\cdot} - \bar{y}_{h\cdot\cdot})}{n_h - 1}$$

and

$$s_{2h}^2 = \frac{\sum_{i=1}^{n_h} \sum_{j=1}^{m_h} (y_{hij} - \bar{y}_{hi\cdot})}{n_h (m_h - 1)}$$

and where $h$ is the index for strata, $i$ is the index for first stage units (transects), $j$ is the index for second stage units (quadrats), $N_h$ is the number of first stage units in the $h^{th}$ stratum, $M_h$ is the number of second stage units in the $h^{th}$ stratum, $W_h$ is the relative weight of stratum $h$ in terms of second stage units, $n_h$ is the number of first stage units selected from stratum $h$, $m_h$ is the number of quadrats in each first stage unit in stratum $h$, $yhij$ is the count in first stage unit $i$ from stratum $h$, $s^2_{1h}$ is the sample variance among first stage units in stratum $h$ and $s^2_{2h}$ is the sample variance between first stage units in stratum $h$.

The approximate 95% confidence interval (CI) for the population mean was estimated as:

$$\bar{y}_{STS} \pm (1.96)\sqrt{\hat{V}(\bar{y}_{STS})} .$$

Survey precision (Norgard et al. 2010) was calculated as:

$$\text{precision} = \left(\frac{CI}{\text{mean}}\right) \times 100$$

where *mean* is the estimated mean density, *CI* is the 95% confidence interval of the mean estimate and precision is expressed as a percentage. Target precision for intertidal surveys was values $\leq 30\%$ (Allen and Davis, unpub. manuscript; Norgard et al. 2010). Precision was reviewed at the end of each survey; depending on results sampling intensity can be increased for subsequent surveys if precision is low. Statistics can be completed to estimate sample size. Also, sites with a large number quadrats without oysters will affect confidence intervals.

Length frequencies were collated and graphed using R code (Appendix 4).

# Results and Discussion

Olympia oyster index sites were selected within four zones (Northwest Vancouver Island, Southwest Vancouver Island, Juan de Fuca Strait and Strait of Georgia) assigned as part of the index site selection process (DFO 2010)(Figure 1). A total of 43 surveys were completed at 14 index sites between 2009 and 2016. Eleven sites have been surveyed three times, two have been surveyed twice, and Gorge Site #9 and Klaskino have been surveyed four times since 2009 (Table 1). Index site maps (Figures 2-15) represent the most current strata configuration; quadrat densities are presented in Tables 2-10.

This report compares bed area, survey design, stratum area, densities, size frequencies, and other parameters for Olympia oyster populations at each beach over multiple survey years. Comparisons of these parameters between beaches have not been done. Index site beaches are not easily comparable for reasons such as beach areas, widely varying densities, and a wide range of habitat types that have not been fully assessed and quantified.

## Northwest Vancouver Island

Index sites for Northwest Vancouver Island include Klaskino Inlet, Port Eliza Beach 3 and Amai Inlet (Figure 1).

### Klaskino Inlet

Location and Habitat Description

This index site is located on the northern shore at the head of Klaskino Inlet (Figure 2). The beach was reported as Beach 1, head of Klaskino Inlet (Northeast) by Gillespie et al. (2004) and Northeast Klaskino by Gillespie and Bourne (2005); and it is classified as beach code 27-05-001.

The beach substrate is comprised of gravel, some larger rocks and shell. Flow from an upland creek discharges through the end of the third stratum. The beach slope is low

throughout most of the intertidal. However, the grade increases quickly at the low tide mark and delineates the most seaward edge of the Olympia oyster bed.

Survey Frequency and Design

All three strata at this site were surveyed in 2010, 2013, 2015 and 2017 (Table 1). The three strata covered 6,080 $m^2$ which represented 57% of the mapped Olympia oyster bed on the eastern end of the beach (Table 2). After the 2010 survey, stratum 1 was reduced in area from 1,750 $m^2$ to 1,680 $m^2$ to eliminate a subtidal portion (Table 3). The number of quadrats in stratum 3 was increased from 80 in 2013 to 99 in 2015 contributing to improved precision, lowering it from 60% in 2013 to 24% in 2015.

Oyster Density

Overall mean density at this site decreased from 9.4 ± 4.3 oysters $m^{-2}$ in 2010 to 4.8 ± 2.0 in 2013, then increased to 10.3 ± 2.8 in 2015 (Table 3). This pattern was primarily due to decreased density in stratum 3 in 2013, as the other strata both showed increasing density trends over three surveys (Figure 3).

Stratum 1 densities increased during the last three surveys (2013-2017) from 0.5 ± 0.6 (2013) to 7.2 ± 3.1 $m^{-2}$ (2017) (Table 3, Figure 3). Stratum 2 density increased over the four surveys and was considerably higher (29.7 ± 11.3) in 2017 than in previous years. Stratum 3 had the highest density over three survey years for 2010, 2013 and 2015 (Table 3, Figure 3).

The lowest densities occurred each year in stratum 1, where wide CIs and high numbers of quadrats with zero oyster counts resulted in low precision values of 131%, 108%, 81% and 43 % for each respective year (Table 3).

Few small oysters (≤ 15mm) were sampled at Klaskino Inlet; zero counts were at least 82% in all strata and all years (Table 4). The highest estimated density of small oysters (1.4 ± 2.2 $m^{-2}$) was Stratum 2 in 2017 (Table 4, Figure 3).

Shell Length

Mean length showed a decreasing trend from 2010 (46.4 ± 1.0 mm) to 2015 (31.8 ± 1.1 mm) (Table 5, Figure 3). Relatively low mean size and increased proportion of oysters ≤ 15 mm in 2015 (Figure 3) suggest a recent recruitment event.

## Amai Inlet

Location and Habitat Description

Amai Inlet is located in Kyuquot Sound on the northwest coast of Vancouver Island (Figure 4). The index site is located on the south side of the head of Amai Inlet. This site was previously reported as Amai Inlet 2 by Gillespie and Bourne (2005) and it is currently classified as beach code 26-03-004. Although there are two suitable Olympia

oyster beds present, the distance between them precluded surveying both; the eastern side of the beach was chosen as the index site.

The beach has a moderate slope and is covered with small rocks and cobble. Although the edges of the oyster bed are not clearly delineated by steep gradients on the seaward side, the density of oysters is greatest in cobble substrate, and decreases substantially at the transition to sand and eelgrass habitat.

Survey Frequency and Design

This site was surveyed in 2010 and 2013 (Table 1). A single stratum (2,000 $m^2$) was surveyed in both years; the survey area represented 48% of the mapped Olympia oyster bed (Table 1).

Oyster Density

Estimated mean density decreased from 36.9 ± 12.8 oysters $m^{-2}$ in 2010 to 6.6 ± 3.1 in 2013 (Table 3, Figure 5.). For 2013, 68% of all quadrats surveys had zero counts which contributed to the poor survey precision of 47%.

The density of small size class oysters was low in 2013 at 0.3 ± 0.4 oysters $m^{-2}$ (Table 4); this size class was not counted separately in 2010.

Shell Length

Mean shell length decreased from 45.7 ± 0.9 mm in 2010 to 40.6 ± 3.4 mm in 2013. (Table 5, Figure 5). Higher CIs for shell length in 2013 are likely due to a combination of a wider range of sizes present and small sample size.

In 2010, there was a relatively even distribution of shell lengths above and below the mean value (Figure 5). The higher number of small oysters in 2013 may indicate a recruitment event.

## Port Eliza Beach 3

Location and Habitat Description

Port Eliza is located on the north side of Esperanza Inlet on northwest Vancouver Island. Beach 3 is located about two thirds of the way up Port Eliza on the east side (Figure 6). This site is currently classified as beach code 25-12-005.

The beach is covered with small rocks and cobble, has a low slope, and has a creek that discharges through the middle of the oyster bed.

Survey Frequency and Design

The beach was surveyed in 2010, 2012 and 2013 (Table 1). In DFO (2010), Beach 2 was recommended as an index site. However, Beach 3 was assigned as the index site because this beach had a longer time series of surveys.

The mapped Olympia oyster bed area was 8,857 $m^2$. During 2010, a single stratum (14 quadrats) was surveyed due to an unfavourable low tide (Table 3). Similarly, in 2013, a single stratum (35 quadrats) was surveyed because additional time was required to count high numbers of oysters within the quadrats, most of which were small (Table 4).

Ideally, the 2012 survey design, which incorporated two strata covering 3,450 $m^2$ (39% of the mapped oyster bed, 45 and 40 quadrats, respectively) (Table 2, Table 3) should be replicated in the future.

Oyster Density

Changes to the number of strata and stratum areas between surveys preclude meaningful comparison of overall density; however, high densities of oysters have been observed each year at this site (Table 3, Figure 7). In stratum 1, the only stratum surveyed in all three years, densities ranged from 170.6 ± 40.7 $m^{-2}$ in 2012 to 507.0 ± 74.1 in 2013. Low numbers of quadrats with zero counts (i.e., 5 in 2012 and 6 in 2013) contributed to narrow CIs and good survey precision values less than 30% (Table 3).

In 2013, a high density of small size class oysters was observed. High density of small size class oysters and the domination of the size frequency distribution by oysters ≤ 15 mm provide evidence of a recent recruitment event (Table 4, Figure 7). Not all small oysters were able to be counted in several quadrats resulting in an underestimation of the density of small oysters.

Low numbers of Pacific oysters observed between 2010 and 2013, provide confidence that the recruitment event was Olympia oysters and not small Pacific oysters.

Shell Length

Mean length is similar for the first two surveys; 32.8 ± 0.7 mm and 33.3 ± 0.6 mm in 2010 and 2012 respectively (Table 5, Figure 7). However, a lower mean length of 7.9 ± 1.0 mm occurred in 2013. Due to high numbers of small oysters and time constraints, not all small oysters in quadrats selected for biological sampling could be measured (all large oysters were measured).

## Southwest Vancouver Island

Index sites for Southwest Vancouver Island include Darr Island, Bacchante Bay, Harris Point, Hillier Island and Joes Bay (Figure 1).

## Darr Island

Location and Habitat Description

Darr Island is located in Stewardson Inlet in northern Clayoquot Sound (Figure 8). This site is currently classified as beach code 24-02-002.

The beach is large with a moderate slope, and a substrate comprised of gravel, cobble and boulders. Only the western edge of the beach was investigated for Olympia oyster. A small area was found with Olympia oyster densities suitable for surveying. Most oysters were attached to boulders and cobble. Olympia and Pacific oysters co-occur on this beach which made identification of small oysters difficult.

Survey Frequency and Design

The site was surveyed in 2010, 2012 and 2015 (Table 1). Stratum area was increased from 125 $m^2$ to 150 $m^2$ and the number of quadrats increased from 30 to 45 after the 2010 survey (Table 6) in an effort to increase survey precision. The 2015 surveyed area comprises 23% of the mapped bed size (Table 2).

Oyster Density

The highest density (18.9 ± 3.9 oysters $m^{-2}$) was observed in 2015 (Table 6). Survey precision improved each year, from 36% in 2010 to 21% in 2015, in part due to increased sampling intensity.

Density of small size class oysters increased each year, although CIs were relatively high in all years (Table 7, Figure 9).

Shell Length

Mean length was similar in the 2010 and 2012 surveys (33.1 ± 1.8 mm and 31.2 ± 2.0 mm respectively) and decreased to 26.3 ± 1.0 mm in 2015 (Table 5, Figure 9). Size frequency in 2015 had a much higher contribution from oysters ≤ 15 mm relative to previous surveys, possibly indicating successful recent recruitment.

## Bacchante Bay

Location and Habitat Description

Bacchante Bay is located in northeastern Clayoquot Sound at the head of Shelter Inlet (Figure 10). This site is currently classified as beach code 24-13-004.

The bay has a large beach with low slope and cobble and gravel substrate. Distribution was patchy and large areas had only scattered single oysters. The survey area has lower elevation with shallow tide pools and relatively high concentration of Olympia oysters observed.

Survey Frequency and Design

In 2010, the survey area included one stratum and 60 quadrats (Table 6). However, in an effort to improve precision, the survey area was divided into three equal sized strata of 240 $m^2$ and an additional 40 quadrats were added in 2012. This design was also used in 2015. The total area surveyed in 2012 and 2015 was 720 $m^2$, which is larger than the 522 $m^2$ mapped bed area (Table 2).

Oyster Density

Density at this index site is low. Overall density increased slightly from 2012 to 2015, but low densities and poor precision do not allow meaningful comparisons. The maximum density observed was 1.7 ± 1.8 oysters $m^{-2}$ in stratum 3 in 2015; the minimum was zero in stratum 1 in 2012 (Table 6, Figure 11).

The low density and patchiness at Bacchante Bay is evident by the high number of zero counts observed (Table 6). The high percentage of zero counts resulted in poor survey precision values for each survey year.

Shell Length

Mean size was highest in 2010 (42.9 ± 1.9 mm) and lowest in 2015 (35.6 ± 4.4 mm) (Table 5). Low sample sizes contributed to relatively high CIs for mean size frequency.

## Harris Point

Location and Habitat Description

Harris Point is located in northeastern Barkley Sound at the mouth of Pipestem Inlet (Figure 12). The index site is a small saddle beach just south of Harris Point. This site is currently classified as beach code 23-10-005.

The beach has a low slope with a substrate of gravel, cobble and boulders. A creek flows from a lagoon in the upper beach and runs through the oyster bed.

This beach has a high abundance of Pacific oysters which co-occur with the Olympia oysters. Larger Pacific oysters were easily distinguished from Olympia oysters. However, difficulties in identifying small oysters may have resulted in overestimation small Olympia oyster densities.

Survey Frequency and Design

Harris Point was surveyed in 2010, 2012 and 2014 (Table 1). The mapped Olympia oyster bed is 761 $m^2$ in area (Table 2). In 2014, the stratum area was reduced from the 2012 are of 300 $m^2$ to 260 $m^2$ and a sampling intensity of 38 quadrats was chosen as the most appropriate to achieve survey precision ≤ 30%. This site has a large Pacific Oyster

bed which complicated defining the Olympia oyster bed boundary so the changes in the stratum occurred as we gained a more clear understanding of this beach.

Oyster Density

Density increased from 47 ± 10.9 oysters $m^{-2}$ in 2010 to 58.1 ± 19.8 and 136.1 ± 33.9 in 2012 and 2014 respectively (Table 6, Figure 13). In each year there were low numbers of quadrats that had zero counts (8%, 18% and 0% respectively).

The lowest density of small size class oysters at 5.4 ± 4.9 oysters $m^{-2}$ was observed in 2012 (size categories were not used in 2010). In 2014, the density of small oysters was considerably higher at 53.9 ± 21.6 oysters $m^{-2}$ likely due to a recruitment event (Table 7, Figure 13).

Shell Length

Mean length of oysters dropped each survey year from 31.3 ± 1.4 mm in 2010 to 27.3 ± 1.6 mm in 2012 and 18.5 ± 1.2 mm in 2014 (Table 5, Figure 13). The 2014 mean length is lower than both means in the previous surveys. In 2014, 42% of oysters measured were in the small size class, providing evidence of recruitment. In comparison, the small size class comprised 2% in 2010 and 3% in 2012.

## Hillier Island

Location and Habitat Description

Hillier Island is located in Toquart Bay in northeast Barkley Sound (Figure 14). This site is currently classified as beach code 23-10-002.

The large beach has a low slope, gravel substrate and a creek that runs adjacent to where strata were located. The beach has patchy distributions of both Olympia and large Pacific oysters.

Survey Frequency and Design

The site was surveyed in 2010, 2012 and 2014 (Table 1). The mapped oyster bed is large, covering an area of 6,759 $m^2$ (Table 2). Stratum size was 2,700 $m^{-2}$ in 2014 and varied little between years (Table 6). The most recent configuration encompasses 40% of the mapped oyster bed. Sampling intensity varied from 120 quadrats (2010), 40 (2012) and 74 (2014) and reflects the time available to complete surveys.

Oyster Density

Density ranged between 44.3 ± 20.7 oysters $m^{-2}$ in 2012 and 64.1 ± 17.5 in 2014 (Table 6, Figure 15). Relatively wide CIs preclude discussion of differences or trends in density.

The highest densities of small oysters was 34.9 ± 24.4 oysters $m^{-2}$ in 2010 and 23.1 ± 9.4 in 2014 both of which are considerably higher than the 2012 density of 0.6 ± 0.6 $m^{-2}$ (Table 7, Figure 15).

Shell Length

Mean length was lowest in 2010 (10.3 ± 0.7 mm), compared to 23.3 ± 0.9 in 2012 and 23.5 ± 2.2 mm in 2014 (Table 5, Figure 15). In 2010, 84% of oysters measured were in the small size class indicating recent recruitment.

## Joes Bay

Location and Habitat Description

Joes Bay is located on the northeast side of Turtle Island in the Broken Group Islands Unit of Pacific Rim National Park Reserve (Figure 16). This site is currently classified as beach code 23-08-002. Surveys at this site are led by Parks Canada Ecologists.

The index site includes a small stratum across a bedrock outcrop between two embayments and a larger stratum in the small bay on north side. Stratum 2 has a moderate slope and its substrate is cobble and gravel.

Survey Frequency and Design

The site was surveyed in 2014, 2015 and 2017 (Table 1). This site was not part of the original set of index sites identified in DFO (2010). Parks Canada and DFO have worked in partnership since 2014 to conduct surveys and monitor Olympia oysters at Joes Bay as part of the Parks Canada Shellfish Monitoring Program. Parks Canada utilizes the same survey methodology and design used by DFO at all index sites.

The mapped Olympia oyster bed is 789 $m^2$ in area of which 593 $m^2$ (75%) was surveyed in 2014 (Table 2). The survey area includes one very small stratum (33 $m^2$) designed to include the narrow band on the southeastern portion across a bedrock outcrop. Stratum 2 is 560 $m^2$ and includes the main part of the beach. In 2015, the boundaries of stratum 2 were shifted seaward into higher quality Olympia oyster habitat.

Oyster Density

Density overall increased from 2014 to 2015 (4.0 ± 2.4 oysters $m^{-2}$ and 10.4 ± 8.2 respectively)(Table 6, Figure 17). In all years, stratum 2 had the highest densities (4.0 ± 2.6 $m^{-2}$, 11.0 ± 8.7 and 33 ± 12.3 respectively). However, poor survey precision limits the utility of comparisons between strata or surveys (Table 6, Figure 17).

Low densities of small oysters were observed in all years. The lowest density was 1.1 ± 1.4 $m^{-2}$ in stratum 1 and the highest was 4.6 ± 3.4 in stratum 2, both in 2015 (Table7, Figure 17).

Shell Length

Size frequency was measured in 2014 and 2017. In 2015, counts of small oysters were completed but individual measurements were not recorded. Size frequency decreased from 35.8 ± 3.0 mm in 2014 to 29.3 ± 0.4 mm in 2017 (Table 5, Figure 17).

## Juan de Fuca Strait

Index sites in Juan de Fuca Strait include Gorge Site 9 and Ayum Creek (Figure 1).

### Gorge Site 9

Location and Habitat Description

The index site is located on the south shore of the Gorge Waterway, approximately 800 m downstream of the Craigflower Bridge (Figure 18). This site is currently classified as beach code 19-01-003.

Olympia oysters were found on cobble, shell and sitting on hard packed and fine substrate areas. Pacific oysters were not observed at this site.

Gorge Site 9 has large subtidal population of Olympia oysters. Oyster distribution along the shore is continuous rather than in distinguishable beds. Oysters are present upstream and downstream of the index site and throughout the Gorge Waterway (Stanton et al. 2011).

Survey Frequency and Design

The index site was surveyed in 2009, 2010, 2011 and 2016 (Table 1). Since 2009 surveys have been conducted in partnership with the World Fisheries Trust (WFT). Survey methods at this site differ from other sites because much of stratum 2 is subtidal. For this reason, and due to the murkiness of the water and easily disturbed fine sediments, the most effective method to count and measure oysters is to collect the top layer of shell, strain to remove sediment and determine if oysters are alive or dead shell.

Survey layout varied due to the complexities of determining the best Olympia oyster habitat to survey within the subtidal. In 2009 and 2010, the survey was completed jointly by DFO and WFT. During these years, two strata (each 125 $m^2$ in area) were surveyed (Table 2, Table 8). Initial sampling intensity was 30 quadrats in 2009 and increased to 82 quadrats in 2010 to improve survey precision. In 2011, WFT completed the survey and used one stratum (375 $m^2$ in area). In 2016, strata 1 and 2 were 125 $m^2$ and 175 $m^2$ in area with sampling intensity of 15 and 20 quadrats respectively.

Oyster Density

Overall density estimates ranged between 43.0 ± 9.3 oysters $m^{-2}$ in 2010 and 153.9 ± 35.9 in 2009 (Table 8, Figure 19), but differences in survey design preclude discussion of differences or trends between strata or years.

The highest densities occurred in stratum 2 for all surveys in which two strata were surveyed. Densities in stratum 2 decreased from 2009 (291.7 ± 70.4 oysters $m^{-2}$) to 2010 (76.8 ± 18.4), then increased in 2016 (143.8 ± 45.0).

Survey precision in stratum 2 was consistently good; 24%, 24% and 31% in 2009, 2010 and 2016 respectively. The lowest density observed for all years was 3.5 ± 2.4 oysters $m^{-2}$ in 2016 within stratum 1.

In 2016, the density of small oysters was low (0.8 ± 0.6 oysters $m^{-2}$ overall) (Table 9, Figure 19). No density data for the small size category of oysters were collected in 2009, 2010, or 2011.

Shell length

Mean size ranged from 32.9 ± 1.4 mm in 2016 to 38.5 ± 0.8 mm in 2010 (Table 5, Figure 19). Smaller sized oysters were more common in 2016 than 2010 or 2011.

## Ayum Creek

Location and Habitat Description

Ayum Creek is located in Cooper Cove in Sooke Basin (Figure 20) and is currently classified as beach code 20-07-003.

The beach has a low slope and a mud and gravel substrate. A small creek originating from a mill pond flows through the middle of the beach.

Survey Frequency and Design

The site was surveyed in 2011, 2012 and 2013 (Table 1). The mapped Olympia oyster bed at this site is 2,567 $m^2$ (Table 2). The survey design included two strata with the smaller stratum 1 (168 $m^2$) directly beside the inflow from the mill pond and stratum 2 (480 $m^2$) located in the intertidal area of the beach. Stratum 1 supported a small patch of Olympia oysters, while stratum 2 contained single oysters scattered across the beach (Figure 20). To improve survey precision, sampling intensity was increased in stratum 1 from 28 quadrats (2011) to 112 (2013) (Table 8, Figure 21). In stratum 2, sampling intensity was increased from 28 (2011) to 32 quadrats (2013).

Oyster Density

Overall density was relatively similar in 2011 and 2012 (13.8 ± 9.8 oysters $m^{-2}$ and 15.3 ± 11.5 respectively), then decreased in 2013 (9.5 ± 7.7)(Table 8, Figure 21). Densities were highest in stratum 1 and increased each survey (28.0 ± 32.3 oysters $m^{-2}$ in 2011 to 36.1 ± 29.6 in 2013). However, densities did not vary considerably between years and low precision suggested that the differences were not significant.

An oyster density of $0.1 \pm 0.2$ oysters $m^{-2}$ in stratum 2 in 2013 was the lowest encountered in both strata over all surveys (Table 8, Figure 21). Poor precision (± 196%) was due to no Olympia oysters counted (zero counts) in the majority of quadrats surveyed (97%).

The density of small oysters in stratum 1 was low in 2011 ($1.1 \pm 2.2$ oysters $m^{-2}$), zero in 2012 and increased in 2013 ($10.0 \pm 4.4$)(Table 9, Figure 21). No small size class oysters were found in stratum 2 in any of the years.

Shell length

In 2011 and 2012 the mean length of oysters were similar ($37 \pm 2.8$ mm and $39.6 \pm 1.1$ mm). However, in 2013 mean size was lower than previous years ($25.3 \pm 2.9$ mm) due to increased frequency of oysters < 25 mm, suggesting a recruitment event (Table 5, Figure 21).

## Strait of Georgia

Olympia oyster index sites in the Strait of Georgia include Jervis Inlet, Baker Bay, Swy-a-Lana Lagoon, and Transfer Beach (Figure 1).

### Jervis Inlet 1

Location and Habitat Description

The Jervis Inlet index site is located on the eastern side of Dacres Point, near Goliath Bay and facing Prince of Wales Reach (Figure 22). This site is currently classified as beach code 16-13-006.

The beach has a moderate to high slope and is covered with boulders and cobble. Ideally, this site should be survey on the lowest available tide. Olympia oysters are sparse, hidden under rocks, and confined to the lower intertidal. Pacific oysters are present but not abundant and co-occur with Olympia oysters on the beach.

Survey Frequency and Design

The site was surveyed in 2011, 2013 and 2014 (Table 1). The mapped Olympia oyster bed is relatively small at this site (493 $m^2$) (Table 2). Survey design changed from a single stratum (180 $m^2$) in 2011 to two equal sized strata (180 $m^2$ each); totalling 360 $m^2$ in 2013 and 2014. The total surveyed area represented 73% of the mapped Olympia oyster bed.

Survey designs in 2013 and 2014 included a baseline that bisected the bed into two strata (Figure 22). Transects were laid perpendicular to the baseline in each stratum. Transects and quadrats were oriented down the beach from the mid to lower intertidal in stratum 1 and up the beach from the lower intertidal to mid intertidal in stratum 2. Sampling intensity increased from 90 quadrats in 2011 to a total of 106 and 101 quadrats in 2013 and 2014 respectively (Table 11).

Oyster Density

In 2011, the density was 4.8 ± 1.9 oysters $m^{-2}$ (Table 10, Figure 22) and oysters were present in very few (10%) of quadrats surveyed (Table 10, Figure 23). Overall densities increased from 2013 to 2014 (4.2 ± 1.3 and 12.5 ± 3.0 oysters $m^{-2}$ respectively).

Densities of small oysters were 3.2 ± 1.6 oysters $m^{-2}$ in 2011 and 8.8 ± 3.4 overall in 2014; no small oysters were encountered in 2013 (Table 5, Table 11, Figure 23).

Shell length

Although mean length increased between 2011 and 2014, small sample sizes, particularly in the first two surveys, preclude discussion of trends (Table 5, Figure 23). Although densities of small size class oysters were relatively high in 2011 and 2014, indicating recruitment events, this is not reflected in the size frequencies for these surveys; in part an artifact of low sample size.

## Baker Bay

Location and Habitat Description

Baker Bay is located at the northern end of Hotham Sound (Figure 24). This site is currently classified as beach code 16-12-007.

The beach has a low slope and is covered with cobble. Two creeks run across the beach; the larger creek crosses the west end of the beach and the smaller creek approximately bisects the beach. Olympia oysters were sparsely distributed and mostly found in the smaller creek and the lower intertidal between the two creeks. Large Pacific oysters were abundant at this site. The Olympia oyster bed is located in the lower intertidal and should ideally be surveyed on a tide < 0.5 m above chart datum.

Survey Frequency and Design

The site was surveyed in 2011, 2013 and 2014 (Table 1). The mapped Olympia oyster bed was small (457 $m^2$) of which 360 $m^2$ has been surveyed (Table 2). In 2011, 87 quadrats were surveyed in stratum 1. In 2013, the bed was divided into two strata and increased survey intensity of 112 quadrats to improve the precision of density estimates Table 10).

The survey design in 2013 and 2014 included placement of a baseline that bisects the bed into two strata (Figure 24). Transects were laid perpendicular to the baseline in each stratum. Stratum 1 was on the seaward side of the baseline and stratum 2 was on the shoreward side. Transects and quadrats were oriented down the beach from the baseline seaward for stratum 1 and up the beach from baseline shoreward for stratum 2.

Oyster Density

Overall densities increased from 8.8 ± 3.2 oysters $m^{-2}$ in 2013 to 88.5 ± 31.8 in 2014 (Table 10, Figure 25). Stratum 1 had higher densities than stratum 2 in both 2013 and

2014. Stratum 2 had the lowest density for all years (2.5 ± 2.0 oysters $m^{-2}$) in 2013 and the majority of quadrats surveyed had no Olympia oysters resulting in poor survey precision of 80% (Table 10).

Overall density of small oysters was high in 2014 (76.7 ± 29.4 oysters $m^{-2}$) relative to 2013 (0.7 ± 0.6) (Table 11, Figure 25). Every quadrat surveyed in stratum 1 in 2014 had small oysters.

Shell length

Mean shell length was lowest in 2011 (16.7 ± 1.1 mm) and lower than in 2013 (19.9 ± 1.0 mm) and 2014 (18.7 ± 2.0 mm)(Table 5, Figure 25). In 2011, 53% of oysters measured were ≤ 15 mm indicating a relatively strong recruitment event. Although small oyster densities were high in 2014 this was not reflected in the size frequency, likely due to small sample size (Table 5, Figure 25).

## Swy-a-Lana Lagoon

Location and Habitat Description

The index site is located in Maffeo Sutton Park in Nanaimo (Figure 26). This site is currently classified as beach code 17-14-002.

Olympia oysters do not form defined beds; they are located within large concrete intertidal terraces that separate Nanaimo Harbour from Swy-a-lana Lagoon. Substrates within each terrace are comprised of boulders, cobble and gravel. All terraces are recessed and remain flooded at low tide. Olympia oyster aggregations have been observed on the subtidal terrace walls on the protected side of the lagoon where they co-occur with Pacific oysters; Olympia oysters are also present on the exposed, Nanaimo Harbour side where few Pacific oysters are present.

Survey Frequency and Design

The site was surveyed in 2010, 2013 and 2016 (Table 1). The site is comprised of three strata totalling 718 $m^2$, with stratum 1 and 2 facing Nanaimo Harbour and stratum 3 positioned on the lagoon side (Table 2, Figure 26).

Oyster Density

Overall densities ranged between 35.5 ± 8.4 oysters $m^{-2}$ in 2013 and 65.2 ± 21.0 in 2016, with no clear trend (Table 10, Figure 27). Densities were highest in stratum 3 for all surveys and peaked at 145.6 ± 26.7 oysters $m^{-2}$ in 2016.

Overall densities of small oysters increased from 0.1 ± 0.2 oysters $m^{-2}$ in 2013 to 1.1 ± 0.6 in 2016. Small oysters were not recorded separately in 2010 (Table 1).

Shell length

Mean length was lowest in 2010 (25.2 ± 1.5 mm) (Table 5, Figure 27). Higher numbers of oysters < 25 mm in 2010 and 2016 suggest recruitment events (Table 5).

### Transfer Beach

Location and Habitat Description

The Transfer Beach index site is located on the south side of Ladysmith Harbour (Figure 28). This site is currently classified as beach code 17-07-023.

The beach is adjacent to Transfer Beach Park and has heavy use by people year round. The substrate is comprised of boulder and cobble and the beach has a moderate slope. Large and small-sized Pacific oyster and Olympia oyster co-exist on this beach. The Olympia oyster bed is located in the lower intertidal and should ideally be surveyed at a tide < 0.5 m above chart datum.

Survey Frequency and Design

The site was surveyed in 2011, 2012 and 2016. The mapped Olympia oyster bed at this site is 1811 $m^2$ of which 720 $m^2$ has been surveyed. Stratum area and placement has varied across surveys. Single strata were surveyed in 2011 and 2016; the 2012 survey was conducted on a much lower tide and stratum 1 was increased in area and a second stratum added (Table 1,Table 2, Figure 28).

Oyster Density

Estimated mean densities appear to have increased with each survey but differences in the size and number of strata preclude meaningful comparisons other than stratum 1 in the final two surveys (Table 10, Figure 29).

The highest density of small oysters was observed in 2016 (14.8 ± 4.7 oysters $m^{-2}$) (Table 11, Figure 29). However, recruitment of Pacific oysters in 2016 and potential identification error of oysters in the small size category reduces confidence that the recruitment event was exclusively Olympia oyster. This may have resulted in an overestimate of the density of small Olympia oyster.

Shell length

Mean shell lengths were similar in 2011 and 2016 (24.1 ± 2.7 mm and 24.7 ± 1.6 mm respectively) (Table 5, Figure 29).

# Conclusions

Primary objectives of this report were to report results of index site surveys, inform evaluation of the SARA management plan, and inform refinement of future survey methods and data collection.

Refinement of the survey design at each site has been completed to optimize the time at each and increase survey precision. Refinements include changes from year to year to survey strata and sampling intensity. Densities and size frequencies have been

reported for each site and year. The time series at most sites is short and precluded evaluation of trends. However, baseline information from index site data and continued monitoring will enable future analysis of variability and trends.

At all sites Olympia oyster were found on subsequent visits and recruitment events were observed at number of sites (Port Eliza Beach #3 2013, Harris Point 2014, Hillier Island 2010, 2014 and Baker Bay 2014). Identification of small oysters was challenging at sites which included larger number of both Pacific and Olympia oysters so a small oyster category (≤15mm) was used to categorize all oysters in which identification error may have occurred (Table 4Table 4Table 7, Table 9 and Table 11). This information was also used to provide evidence of recruitment events.

Low density sites tend to have increased number of 'zero' quadrats with no oysters found and therefore have survey poor precisions much greater than 30%. To increase precision the number of surveyed quadrats on subsequent visits was increased. In some cases this improved survey precision. However, increased survey effort may negatively impact oyster populations and habitat by increased survey traffic over the bed but individual oyster mortality is limited from survey handling because sampling is done on site. Sites will need to have time to recover between surveys, suggesting that surveys occur no more than every 3rd year at low density sites.

Continued monitoring is necessary to meet the objectives of the SARA management plan and data collected will be essential in informing a new management plan. If time allows, increased bio-sample measurements (at least 100 per site) will allow more robust estimates of size distributions at each site. Improvement of substrate and habitat information, including temperature and salinity, at each site would be valuable. Exploration of impacts of invasive species on Olympia oysters would benefit from continued collection of data on presence and abundance of these species.

# Acknowledgements

This work was funded by the DFO SARA Monitoring Program, with support from the Parks Canada Shellfish Monitoring Program and World Fisheries Trust. We thank Jennifer Yakimishyn (Parks Canada) and Joachim Carolsfeld, Laura Kravac, Alica Donaldson and Amanda Fentiman (World Fisheries Trust) for collaborating on surveys and sharing data. We also thank the Captains Mike Corfield, Zibogniew Chmara, Duncan McCalum, Simon Dockerill and crew of the CCGS Vector for their support in remote surveys. Each survey takes of crew of 3 to 6 people, so we would like to thank the many colleagues who worked on these surveys with us.

# References


Allen, B.L. and J.P. Davis. Unpubl. manuscr. Intertidal *Ostrea conchaphila* population assessment procedures; applications for surveying natural populations and restoration areas.

Bourne, N. 1997. Molluscan fisheries of British Columbia. NOAA Tech. Rep. NMFS 128: 115-130. Available online: http://spo.nmfs.noaa.gov/Technical%20Report/tr128.pdf.

COSEWIC. 2011. COSEWIC assessment and status report on the Olympia oyster *Ostrea conchaphila* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 56 pp. Available online: http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_olympia_oyster_0911_eng.pdf.

DFO. 2009. Management plan for the Olympia oyster (*Ostrea conchaphila*) in Canada. Species at Risk Act Management Plan Series. Fisheries and Oceans Canada, Ottawa. v + 31 p. Available online: https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/mp_olympia_oyster_0509_e.pdf.

DFO. 2010. Rationale for index site selection for Olympia Oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/053. 10 p. Available online: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2010/2010_053-eng.html.

Ellis, D.W. and L. Swan. 1981. Teachings of the tides: uses of marine invertebrates by the Manhousat people. Theytus Books, Nanaimo BC. 118 p.

Finney, J.L., T.C. Norgard, P.D.G. Boutillier, S.E.M. MacConnachie and G.E. Gillespie. 2012. Field verification of historic records of Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2010 and 2011. Can. Tech. Rep. Fish. Aquat. Sci. 3011: vii + 91 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/347603.pdf.

Gillespie, G.E. 1999. Status of the Olympia oyster, *Ostrea conchaphila*, in Canada. Can. Stock Assess. Secretar. Res. Doc. 99/150. 33 p. Available online: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/1999/pdf/99_150e.pdf.

Gillespie, G.E. 2009. Status of the Olympia oyster, *Ostrea lurida* Carpenter 1864, in British Columbia, Canada. J. Shellfish Res. 28(1): 59-68.

Gillespie, G.E. and N.F. Bourne. 2005. Exploratory intertidal bivalve surveys in British Columbia – 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2733. xi + 199 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/318598.pdf.

Gillespie, G.E. and A.R. Kronlund. 1999. A manual for intertidal clam surveys. Can. Tech. Rep. Fish. Aquat. Sci. 2270. x + 144 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/234406.pdf.

Gillespie, G.E., N.F. Bourne and B. Rusch. 2004. Exploratory intertidal bivalve surveys in British Columbia – 2000 and 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. 2681. ix + 120 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/280731.pdf.

Harbo, R.M. 1997. Shells and shellfish of the Pacific Northwest. Harbour Publishing, Madiera Park BC. 270 p.

Harbo, R., K. Marcus and T. Boxwell. 1997a. Intertidal clam resources (Manila, littleneck and butter clam). Vol. I: the west coast of Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 2416. viii + 116 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/222293.pdf.

Harbo, R., K. Marcus and T. Boxwell. 1997b. Intertidal clam resources (Manila, littleneck and butter clam). Vol. II: the southern inside waters of Vancouver Island and the British Columbia mainland. Can. Manuscr. Rep. Fish. Aquat. Sci. 2417. viii + 245 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/226484.pdf.

Norgard, T., S. Davies, L. Stanton and G.E. Gillespie. 2010. Evaluation of survey methodologies for monitoring Olympia Oyster (*Ostrea lurida* Carpenter, 1864) populations in British Columbia. Can. Sci. Advis. Sec. Res. Doc. 2010/006. iv +56 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/340695.pdf.

Quayle, D.B. 1988. Pacific oyster culture in British Columbia. Can. Bull. Fish. Aquat. Sci. 218. 241 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/109165.pdf.

Stanton, L.M., T.C. Norgard, S.E.M. MacConnachie and G.E. Gillespie. 2011. Field verification of historic records of Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia - 2009. Can. Tech. Rep. Fish. Aquat. Sci. 2940: vi + 115 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/344226.pdf.

**Table 1. Survey dates for Olympia oyster index sites, 2009-2017.**

| Index Sites | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|
| **Northwest Vancouver Island** | | | | | | | | | |
| Klaskino Inlet | | May 30 | | | May 24 | | Jun. 1 | | May 17 |
| Amai Inlet | | Jun 1 | | | May 23 | | | | |
| Port Eliza Beach 3 | | Jun 2 | | Aug1-2 | May 26 | | | | |
| **Southwest Vancouver Island** | | | | | | | | | |
| Darr Island | | Jun 10 | | Jul 18 | | | Jul 14 | | |
| Bacchante Bay | | Jun 11 | | Jul 19 | | | Jul 15 | | |
| Harris Point | | Jun 14 | | Jul 4 | | Jun 28 | | | |
| Hillier Island | | Jun 15 | | Jul 3 | | Jun 27 | | | |
| Joes Bay | | | | | | Jun 25 | Jul 4 | | May 26 |
| **Juan de Fuca Strait** | | | | | | | | | |
| Ayum Creek | | | Jul 4 | May 10 | May 24 | | | | |
| Gorge Site 9 | Jul 7 | Jul 15 | Jul 12 | | | | | Jul 27 | |
| **Strait of Georgia** | | | | | | | | | |
| Baker Bay | | | Jul 13 | | Jun 8 | Jun 13 | | | |
| Jervis Inlet 1 | | | Jul 12 | | Jun 7 | Jun 14 | | | |
| Swy-a-lana Lagoon | | Aug 24 | | | Sep 18 | | | Jul 19 | |
| Transfer Beach | | | Jul 5 | May 9 | | | | Jul 20 | |

**Table 2. Calculated Oyster bed area ($m^2$) from GPS survey, total area surveyed ($m^2$) and percentage of the bed area surveyed for Olympia oyster index sites.**

| Index Site | Bed Area ($m^2$) | Total Area Surveyed ($m^2$) | % of Bed Surveyed |
|---|---|---|---|
| **Northwest Vancouver Island** | | | |
| Klaskino Inlet (2015) | 10,601 | 6,080 | 57% |
| Amai Inlet (2013) | 4,139 | 2,000 | 48% |
| Port Eliza Beach 3 (2012) | 8,857 | 3,450 | 39% |
| **Southwest Vancouver Island** | | | |
| Darr Island (2015) | 651 | 150 | 23% |
| Bacchante Bay (2015) | 522 | 720 | 100% |
| Harris Point (2014) | 761 | 260 | 34% |
| Hillier Island (2014) | 6,759 | 2,700 | 40% |
| Joes Bay (2014) | 789 | 593 | 75% |
| **Juan de Fuca Strait** | | | |
| Ayum Creek (2013) | 2,567 | 648 | 25% |
| Gorge Waterway Site # 9 (2016) | - | 300 | - |
| **Strait of Georgia** | | | |
| Jervis Inlet 1 (2014) | 493 | 360 | 73% |
| Baker Bay (2014) | 457 | 360 | 79% |
| Swy-a-lana Lagoon (2016) | - | 718 | - |
| Transfer Beach (2016) | 1811 | 720 | 40% |

Notes:

- Bed Area comes from calculation of area from the GPS survey of the bed.
- Total Area is the sum of all strata areas at each site.
- Year in brackets () is the survey year that bed area was most recently calculated.
- Gorge Waterway and Swy-a-lana Lagoon sites do not have defined beds.

**Table 3. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in Northwest Vancouver Island 2010-2017.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Klaskino Inlet | 2010 | 1 | 70x25 | 1,750 | 30 | 0.25 | 82% | 0.5 | 0.7 | 131% |
| | | 2 | 80x30 | 2,400 | 48 | 0.25 | 75% | 2.9 | 1.0 | 35% |
| | | 3 | 100x20 | 2,000 | 80 | 0.25 | 45% | 24.8 | 13.1 | 53% |
| | | Overall | | | | | | 9.4 | 4.3 | 46% |
| | 2013 | 1 | 70x24 | 1,680 | 30 | 0.25 | 87% | 0.5 | 0.6 | 108% |
| | | 2 | 80x30 | 2,400 | 40 | 0.25 | 55% | 4.8 | 2.8 | 58% |
| | | 3 | 100x20 | 2,000 | 80 | 0.25 | 50% | 8.4 | 5.0 | 60% |
| | | Overall | | | | | | 4.8 | 2.0 | 42% |
| | 2015 | 1 | 70x24 | 1,680 | 30 | 0.25 | 63% | 3.1 | 2.5 | 81% |
| | | 2 | 80x30 | 2,400 | 35 | 0.25 | 34% | 10.9 | 6.0 | 56% |
| | | 3 | 100x20 | 2,000 | 99 | 0.25 | 33% | 15.8 | 3.7 | 24% |
| | | Overall | | | | | | 10.3 | 2.8 | 27% |
| | 2017 | 1 | 70x24 | 1,680 | 29 | 0.25 | 41% | 7.2 | 3.1 | 43% |
| | | 2 | 80x30 | 2,400 | 14 | 0.25 | 0% | 29.7 | 11.3 | 38% |
| | | 3 | 100x20 | 2,000 | 20 | 0.25 | 25% | 20.8 | 9.0 | 45% |
| | | Overall | | | | | | 20.6 | 5.4 | 26% |
| Amai Inlet | 2010 | 1 | 100x20 | 2,000 | 80 | 0.25 | 31% | 36.9 | 12.8 | 35% |
| | 2013 | 1 | 100x20 | 2,000 | 80 | 0.25 | 68% | 6.6 | 3.1 | 47% |
| Port Eliza Beach 3 | 2010 | 1 | 20x60 | 1,200 | 14 | 0.25 | 0% | 278.9 | 73.5 | 26% |
| | 2012 | 1 | 50x37 | 1,850 | 45 | 0.25 | 11% | 170.6 | 40.7 | 24% |
| | | 2 | 50x32 | 1,600 | 40 | 0.25 | 0% | 316.2 | 55.7 | 18% |
| | | Overall | | | | | | 238.1 | 33.8 | 14% |
| | 2013 | 1 | 37x50 | 1,850 | 35 | 0.25 | 17% | 507.0 | 74.1 | 15% |

**Table 4. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in Northwest Vancouver Island 2010-2017.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Klaskino | 2010 | - | | - | - | - | - | - | - | |
| Inlet | 2013 | 1 | 70x24 | 1,680 | 30 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 80x30 | 2,400 | 40 | 0.25 | 98% | 0.1 | 0.2 | 196% |
| | | 3 | 100x20 | 2,400 | 80 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.0 | 0.1 | 196% |
| | 2015 | 1 | 70x24 | 1,680 | 30 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 80x30 | 2,400 | 35 | 0.25 | 97% | 0.1 | 0.2 | 200% |
| | | 3 | 100x20 | 2,000 | 99 | 0.25 | 82% | 1.2 | 0.7 | 50% |
| | | Overall | | | | | | 0.4 | 0.2 | 53% |
| | 2017 | 1 | 70x24 | 1,680 | 29 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 80x30 | 2,400 | 14 | 0.25 | 98% | 1.4 | 2.2 | 157% |
| | | 3 | 100x20 | 2,000 | 20 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.6 | 0.9 | 150% |
| Amai | 2010 | - | | - | - | - | - | - | - | - |
| Inlet | 2013 | 1 | 100x20 | 2,000 | 80 | 0.25 | 98% | 0.3 | 0.4 | 143% |
| Port Eliza | 2010 | - | | - | - | - | - | - | - | - |
| Beach 3 | 2012 | 1 | 50x37 | 1,850 | 45 | 0.25 | 73% | 2.0 | 0.9 | 47% |
| | | 2 | 50x32 | 1,600 | 40 | 0.25 | 78% | 5.8 | 4.8 | 83% |
| | | Overall | | | | | | 3.7 | 2.3 | 62% |
| | 2013 | 1 | 37x50 | 1,850 | 35 | 0.25 | 3% | 347.5 | 15.8 | 33% |

Note: Small size class was not recorded separately at Klaskino Inlet, Amai Inlet or Port Eliza Beach3 in 2010.

**Table 5. Mean, variability and range of Olympia oyster shell length (mm) at index sites in British Columbia, 2009-2017.**

| Index Site | Year | n | Mean (mm) | ± 95% CI | Min (mm) | Max (mm) |
|---|---|---|---|---|---|---|
| Klaskino Inlet | 2010 | 172 | 46.4 | 1.0 | 15 | 66 |
| | 2013 | 63 | 40.9 | 2.1 | 20 | 55 |
| | 2015 | 478 | 31.8 | 1.1 | 7 | 65 |
| | 2017 | 155 | 33.8 | 1.7 | 8 | 61 |
| Amai Inlet | 2010 | 157 | 45.7 | 0.9 | 31 | 66 |
| | 2013 | 53 | 40.6 | 3.4 | 5 | 56 |
| Port Eliza | 2010 | 976 | 32.8 | 0.7 | 3 | 58 |
| Beach #3 | 2012 | 658 | 33.3 | 0.6 | 6 | 54 |
| | 2013 | 175 | 7.9 | 1.0 | 2 | 44 |
| Darr Island | 2010 | 86 | 33.1 | 1.8 | 4 | 51 |
| | 2012 | 47 | 31.2 | 2.0 | 18 | 50 |
| | 2015 | 186 | 26.3 | 1.0 | 12 | 45 |
| Bacchante | 2010 | 50 | 42.9 | 1.9 | 23 | 58 |
| Bay | 2012 | 19 | 38.3 | 3.2 | 24 | 51 |
| | 2015 | 32 | 35.6 | 4.4 | 9 | 54 |
| Harris Point | 2010 | 75 | 31.3 | 1.4 | 10 | 44 |
| | 2012 | 87 | 27.3 | 1.6 | 11 | 48 |
| | 2014 | 205 | 18.5 | 1.1 | 3 | 42 |
| Hillier Island | 2010 | 621 | 10.3 | 0.7 | 1 | 50 |
| | 2012 | 195 | 23.3 | 0.9 | 8 | 39 |
| | 2014 | 89 | 23.5 | 2.2 | 2 | 41 |
| Joes Bay | 2014 | 58 | 35.8 | 3.0 | 4 | 56 |
| | 2017 | 460 | 29.3 | 0.4 | 3 | 86 |
| Gorge Site #9 | 2009 | 173 | 33.7 | 0.9 | 21 | 64 |
| | 2010 | 212 | 38.5 | 0.8 | 19 | 56 |
| | 2011 | 77 | 38.4 | 1.2 | 27 | 53 |
| | 2016 | 133 | 32.9 | 1.4 | 7 | 57 |
| Ayum Creek | 2011 | 39 | 37.0 | 2.8 | 12 | 58 |
| | 2012 | 136 | 39.6 | 1.1 | 14 | 61 |
| | 2013 | 82 | 25.3 | 2.9 | 7 | 56 |
| Jervis Inlet | 2011 | 27 | 12.1 | 2.9 | 3 | 30 |
| | 2013 | 52 | 16.5 | 1.3 | 9 | 30 |
| | 2014 | 102 | 21.8 | 1.2 | 10 | 43 |
| Baker Bay | 2011 | 159 | 16.7 | 1.1 | 5 | 37 |
| | 2013 | 122 | 19.9 | 1.0 | 8 | 42 |
| | 2014 | 81 | 18.7 | 2.0 | 6 | 43 |
| Swy-A-Lana | 2010 | 135 | 25.2 | 1.5 | 4 | 49 |
| Lagoon | 2013 | 130 | 34.6 | 1.1 | 17 | 51 |
| | 2016 | 149 | 31.3 | 1.4 | 3 | 55 |
| Transfer | 2011 | 56 | 24.1 | 2.7 | 8 | 54 |
| Beach | 2012 | 195 | 16.7 | 1.5 | 3 | 62 |
| | 2016 | 131 | 24.7 | 1.6 | 7 | 54 |

**Table 6. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in Southwest Vancouver Island 2010-2017.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Darr Island | 2010 | 1 | 25x5 | 125 | 30 | 0.25 | 30% | 14.4 | 5.3 | 36% |
| | 2012 | 1 | 25x6 | 150 | 45 | 0.25 | 31% | 8.8 | 3.0 | 35% |
| | 2015 | 1 | 25x6 | 150 | 45 | 0.25 | 18% | 18.9 | 3.9 | 21% |
| Bacchante Bay | 2010 | 1 | 60x12 | 720 | 60 | 0.25 | 82% | 1.1 | 0.6 | 56% |
| | 2012 | 1 | 20x12 | 240 | 20 | 0.25 | 100% | 0 | - | - |
| | | 2 | 20x12 | 240 | 40 | 0.25 | 78% | 1.6 | 1.0 | 61% |
| | | 3 | 20x12 | 240 | 40 | 0.25 | 95% | 0.3 | 0.4 | 139% |
| | | Overall | | | | | | 0.6 | 0.4 | 56% |
| | 2015 | 1 | 20x12 | 240 | 20 | 0.25 | 95% | 0.4 | 0.8 | 196% |
| | | 2 | 20x12 | 240 | 40 | 0.25 | 85% | 1.3 | 1.2 | 90% |
| | | 3 | 20x12 | 240 | 40 | 0.25 | 85% | 1.7 | 1.8 | 106% |
| | | Overall | | | | | | 1.1 | 0.8 | 67% |
| Harris Point | 2010 | 1 | 10x25 | 250 | 40 | 0.25 | 8% | 47.0 | 10.9 | 23% |
| | 2012 | 1 | 25x12 | 300 | 28 | 0.25 | 18% | 58.1 | 19.4 | 33% |
| | 2014 | 1 | 26x10 | 260 | 38 | 0.25 | 0% | 136.1 | 33.9 | 25% |
| Hillier Island | 2010 | 1 | 70x39 | 2,730 | 120 | 0.25 | 28% | 62.4 | 29.7 | 48% |
| | 2012 | 1 | 70x36 | 2,520 | 40 | 0.25 | 30% | 44.3 | 20.7 | 47% |
| | 2014 | 1 | 75x36 | 2,700 | 74 | 0.25 | 7% | 64.1 | 17.5 | 27% |
| Joes Bay | 2014 | 1 | 11x3 | 33 | 15 | 0.25 | 87% | 3.2 | 3.7 | 114% |
| | | 2 | 35x16 | 560 | 60 | 0.25 | 75% | 4.0 | 2.6 | 64% |
| | | Overall | | | | | | 4.0 | 2.4 | 61% |
| | 2015 | 1 | 11x3 | 33 | 21 | 0.25 | 90% | 2.1 | 2.8 | 133% |
| | | 2 | 35x15 | 525 | 27 | 0.25 | 48% | 11.0 | 8.7 | 79% |
| | | Overall | | | | | | 10.4 | 8.2 | 79% |
| | 2017 | 2 | 35x15 | 525 | 60 | 0.25 | 20% | 33.0 | 12.3 | 37% |

**Table 7. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in Southwest Vancouver Island 2010-2017.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Darr Island | 2010 | - | | - | - | - | - | - | - | - |
| | 2012 | 1 | 25x6 | 150 | 45 | 0.25 | 87% | 0.6 | 0.5 | 81% |
| | 2015 | 1 | 25x6 | 150 | 45 | 0.25 | 62% | 2.4 | 1.1 | 48% |
| Bacchante Bay | 2010 | - | | - | - | - | - | - | - | - |
| | 2012 | 1 | 20x12 | 240 | 20 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 20x12 | 240 | 40 | 0.25 | 100% | 0.0 | - | - |
| | | 3 | 20x12 | 240 | 40 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.0 | - | - |
| | 2015 | 1 | 20x12 | 240 | 20 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 20x12 | 240 | 40 | 0.25 | 100% | 0.0 | - | - |
| | | 3 | 20x12 | 240 | 40 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.0 | - | - |
| Harris Point | 2010 | 1 | | - | - | - | - | - | - | - |
| | 2012 | 1 | 25x12 | 300 | 28 | 0.25 | 61% | 5.4 | 4.9 | 91% |
| | 2014 | 1 | 26x10 | 260 | 40 | 0.25 | 13% | 53.9 | 21.1 | 39% |
| Hillier Island | 2010 | 1 | 70x39 | 2,730 | 120 | 0.25 | 73% | 34.9 | 24.4 | 70% |
| | 2012 | 1 | 70x36 | 2,520 | 40 | 0.25 | 90% | 0.6 | 0.6 | 100% |
| | 2014 | 1 | 75x36 | 2,700 | 74 | 0.25 | 27% | 23.1 | 9.4 | 40% |
| Joes Bay | 2014 | 1 | 11x3 | 33 | 15 | 0.25 | 60% | 1.9 | 1.8 | 95% |
| | | 2 | 35x16 | 560 | 60 | 0.25 | 78% | 2.1 | 1.7 | 83% |
| | | Overall | | | | | | 2.1 | 1.6 | 79% |
| | 2015 | 1 | 11x3 | 33 | 21 | 0.25 | 76% | 1.1 | 1.4 | 126% |
| | | 2 | 35x15 | 525 | 27 | 0.25 | 52% | 4.6 | 3.4 | 72% |
| | | Overall | | | | | | 4.4 | 3.1 | 71% |
| | 2017 | 2 | 35x15 | 525 | 60 | 0.25 | 70% | 2.7 | 1.6 | 60% |

Note: Small size class was not recorded separately at Darr Island, Bacchante Bay and Harris point in 2010.

**Table 8. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in Juan de Fuca Strait 2009-2016.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Gorge Site # 9 | 2009 | 1 | 25x5 | 125 | 15 | 0.25 | 53% | 16.0 | 13.8 | 86% |
| | | 2 | 25x5 | 125 | 15 | 0.25 | 0% | 291.7 | 70.4 | 24% |
| | | Overall | | | | | | 153.9 | 35.9 | 23% |
| | 2010 | 1 | 25x5 | 125 | 50 | 0.25 | 66% | 9.3 | 4.3 | 46% |
| | | 2 | 25x5 | 125 | 32 | 0.25 | 6% | 76.8 | 18.1 | 24% |
| | | Overall | | | | | | 43.0 | 9.3 | 22% |
| | 2011 | 1 | 25x15 | 375 | 16 | 0.25 | 44% | 23.5 | 11.8 | 50% |
| | 2016 | 1 | 25x5 | 125 | 15 | 0.25 | 67% | 3.5 | 2.4 | 69% |
| | | 2 | 25x7 | 175 | 20 | 0.25 | 6% | 143.8 | 44.0 | 31% |
| | | Overall | | | | | | 85.3 | 25.7 | 30% |
| Ayum Creek | 2011 | 1 | 17x14 | 238 | 28 | 0.0625 | 68% | 28.0 | 32.3 | 115% |
| | | 2 | 36x16 | 576 | 28 | 0.0625 | 61% | 8.0 | 3.9 | 48% |
| | | Overall | | | | | | 13.8 | 9.8 | 71% |
| | 2012 | 1 | 12x14 | 168 | 109 | 0.25 | 50% | 35.2 | 20.2 | 58% |
| | | 2 | 30x16 | 480 | 32 | 0.25 | 72% | 8.4 | 13.8 | 165% |
| | | Overall | | | | | | 15.3 | 11.5 | 75% |
| | 2013 | 1 | 12x14 | 168 | 112 | 0.25 | 47% | 36.1 | 29.6 | 82% |
| | | 2 | 30x16 | 480 | 32 | 0.25 | 97% | 0.1 | 0.2 | 196% |
| | | Overall | | | | | | 9.5 | 7.7 | 81% |

**Table 9. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in Juan de Fuca Strait 2009-2016.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Gorge Site #9 | 2009 | - | | - | - | - | - | - | - | - |
| | 2010 | - | | - | - | - | - | - | - | - |
| | 2011 | - | | - | - | - | - | - | - | - |
| | 2016 | 1 | 25x5 | 125 | 15 | 0.25 | 93% | 0.5 | 1.0 | 200% |
| | | 2 | 25x7 | 175 | 20 | 0.25 | 75% | 1.0 | 0.6 | 60% |
| | | Overall | | | | | | 0.8 | 0.6 | 70% |
| Ayum Creek | 2011 | 1 | 17x14 | 238 | 28 | 0.0625 | 96% | 1.1 | 2.2 | 196% |
| | | 2 | 36x16 | 576 | 28 | 0.0625 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.3 | 0.7 | 196% |
| | 2012 | 1 | 12x14 | 168 | 109 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 30x16 | 480 | 32 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.0 | - | - |
| | 2013 | 1 | 12x14 | 168 | 112 | 0.25 | 58% | 10.0 | 4.4 | 44% |
| | | 2 | 30x16 | 480 | 32 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 2.6 | 1.2 | 44% |

Note: The small size class was not recorded separately at Gorge Site #9 in 2009-2011.

**Table 10. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in the Strait of Georgia 2010-2016.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Jervis Inlet | 2011 | 1 | 60x3 | 180 | 90 | 0.0625 | 90% | 4.8 | 1.9 | 40% |
| | 2013 | 1 | 60x3 | 180 | 37 | 0.25 | 35% | 5.4 | 2.2 | 41% |
| | | 2 | 60x3 | 180 | 69 | 0.25 | 59% | 3.1 | 1.2 | 40% |
| | | Overall | | | | | | 4.2 | 1.3 | 30% |
| | 2014 | 1 | 60x3 | 180 | 59 | 0.25 | 44% | 16.1 | 4.2 | 26% |
| | | 2 | 60x3 | 180 | 42 | 0.25 | 76% | 8.9 | 4.3 | 48% |
| | | Overall | | | | | | 12.5 | 3.0 | 24% |
| Baker Bay | 2011 | 1 | 60x3 | 180 | 87 | 0.0625 | 59% | 35.7 | 13.7 | 39% |
| | 2013 | 1 | 60x3 | 180 | 52 | 0.25 | 38% | 15.1 | 6.0 | 40% |
| | | 2 | 60x3 | 180 | 60 | 0.25 | 82% | 2.5 | 2.0 | 77% |
| | | Overall | | | | | | 8.8 | 3.2 | 36% |
| | 2014 | 1 | 60x3 | 180 | 20 | 0.25 | 25% | 153.6 | 61.9 | 40% |
| | | 2 | 60x3 | 180 | 30 | 0.25 | 63% | 23.5 | 14.5 | 62% |
| | | Overall | | | | | | 88.5 | 31.8 | 36% |
| Swy-a-Lana Lagoon | 2010 | 1 | 20x7.5 | 150 | 24 | 0.25 | 38% | 7.7 | 5.8 | 76% |
| | | 2 | 28x10 | 280 | 32 | 0.25 | 22% | 5.5 | 1.9 | 34% |
| | | 3 | 48x6 | 288 | 36 | 0.25 | 6% | 106.9 | 39.7 | 37% |
| | | Overall | | | | | | 46.6 | 16.0 | 34% |
| | 2013 | 1 | 20x7.5 | 150 | 24 | 0.25 | 54% | 3.7 | 2.0 | 53% |
| | | 2 | 28x10 | 280 | 32 | 0.25 | 50% | 5.4 | 3.2 | 60% |
| | | 3 | 48x6 | 288 | 36 | 0.25 | 22% | 81.3 | 20.7 | 25% |
| | | Overall | | | | | | 35.5 | 8.4 | 24% |
| | 2016 | 1 | 20x7.5 | 150 | 29 | 0.25 | 28% | 12.3 | 6.4 | 52% |
| | | 2 | 28x10 | 280 | 30 | 0.25 | 33% | 10.9 | 5.4 | 50% |
| | | 3 | 48x6 | 288 | 35 | 0.25 | 0% | 145.6 | 52.4 | 36% |
| | | Overall | | | | | | 65.2 | 21.0 | 32% |
| Transfer Beach | 2011 | 1 | 60x7 | 420 | 60 | 0.0625 | 60% | 14.9 | 6.1 | 41% |
| | 2012 | 1 | 60x12 | 720 | 30 | 0.25 | 23% | 17.2 | 8.6 | 50% |
| | | 2 | 60x8 | 480 | 47 | 0.25 | 23% | 26.1 | 10.6 | 41% |
| | | Overall | | | | | | 20.8 | 6.7 | 32% |
| | 2016 | 1 | 60x12 | 720 | 44 | 0.25 | 11% | 60.5 | 27.6 | 46% |

**Table 11. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in the Strait of Georgia 2010-2016.**

| Index Site | Year | Stratum | Stratum Size (m) | Stratum Area ($m^2$) | # Quad-rats | Quadrat Size ($m^2$) | Zero Oyster Count | Density (# $m^{-2}$) | 95% CI | Survey Pre-cision |
|---|---|---|---|---|---|---|---|---|---|---|
| Jervis Inlet | 2011 | 1 | 60x3 | 180 | 90 | 0.0625 | 84% | 3.2 | 1.6 | 51% |
| | 2013 | 1 | 60x3 | 180 | 37 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 60x3 | 180 | 69 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.0 | - | - |
| | 2014 | 1 | 60x3 | 180 | 59 | 0.25 | 46% | 9.9 | 4.8 | 49% |
| | | 2 | 60x3 | 180 | 42 | 0.25 | 52% | 7.7 | 4.7 | 61% |
| | | Overall | | | | | | 8.8 | 3.4 | 39% |
| Baker Bay | 2011 | 1 | 60x3 | 180 | 87 | 0.0625 | 77% | 8.8 | 4.9 | 56% |
| | 2013 | 1 | 60x3 | 180 | 52 | 0.25 | 88% | 1.1 | 1.2 | 116% |
| | | 2 | 60x3 | 180 | 60 | 0.25 | 95% | 0.3 | 0.4 | 112% |
| | | Overall | | | | | | 0.7 | 0.6 | 87% |
| | 2014 | 1 | 60x3 | 180 | 20 | 0.25 | 0% | 135.6 | 63.6 | 47% |
| | | 2 | 60x3 | 180 | 30 | 0.25 | 57% | 17.9 | 12.8 | 71% |
| | | Overall | | | | | | 76.7 | 29.4 | 38% |
| Swy-a-Lana Lagoon | 2010 | - | | - | - | - | - | - | - | - |
| | 2013 | 1 | 20x7.5 | 150 | 24 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 28x10 | 280 | 32 | 0.25 | 97% | 0.3 | 0.5 | 196% |
| | | 3 | 48x6 | 288 | 36 | 0.25 | 97% | 0.1 | 0.2 | 196% |
| | | Overall | | | | | | 0.1 | 0.2 | 148% |
| | 2016 | 1 | 20x7.5 | 150 | 29 | 0.25 | 90% | 0.6 | 0.6 | 100% |
| | | 2 | 28x10 | 280 | 30 | 0.25 | 77% | 2.0 | 1.2 | 60% |
| | | 3 | 48x6 | 288 | 35 | 0.25 | 94% | 0.6 | 0.9 | 158% |
| | | Overall | | | | | | 1.1 | 0.6 | 54% |
| Transfer Beach | 2011 | 1 | 60x7 | 420 | 60 | 0.0625 | 92% | 2.1 | 2.7 | 127% |
| | 2012 | 1 | 60x12 | 720 | 30 | 0.25 | 100% | 0.0 | - | - |
| | | 2 | 60x8 | 480 | 47 | 0.25 | 100% | 0.0 | - | - |
| | | Overall | | | | | | 0.0 | - | - |
| | 2016 | 1 | 60x12 | 720 | 44 | 0.25 | 18% | 14.8 | 4.7 | 32% |

Note: The small size class was not recorded separately at Swy-a-lana Lagoon in 2010.

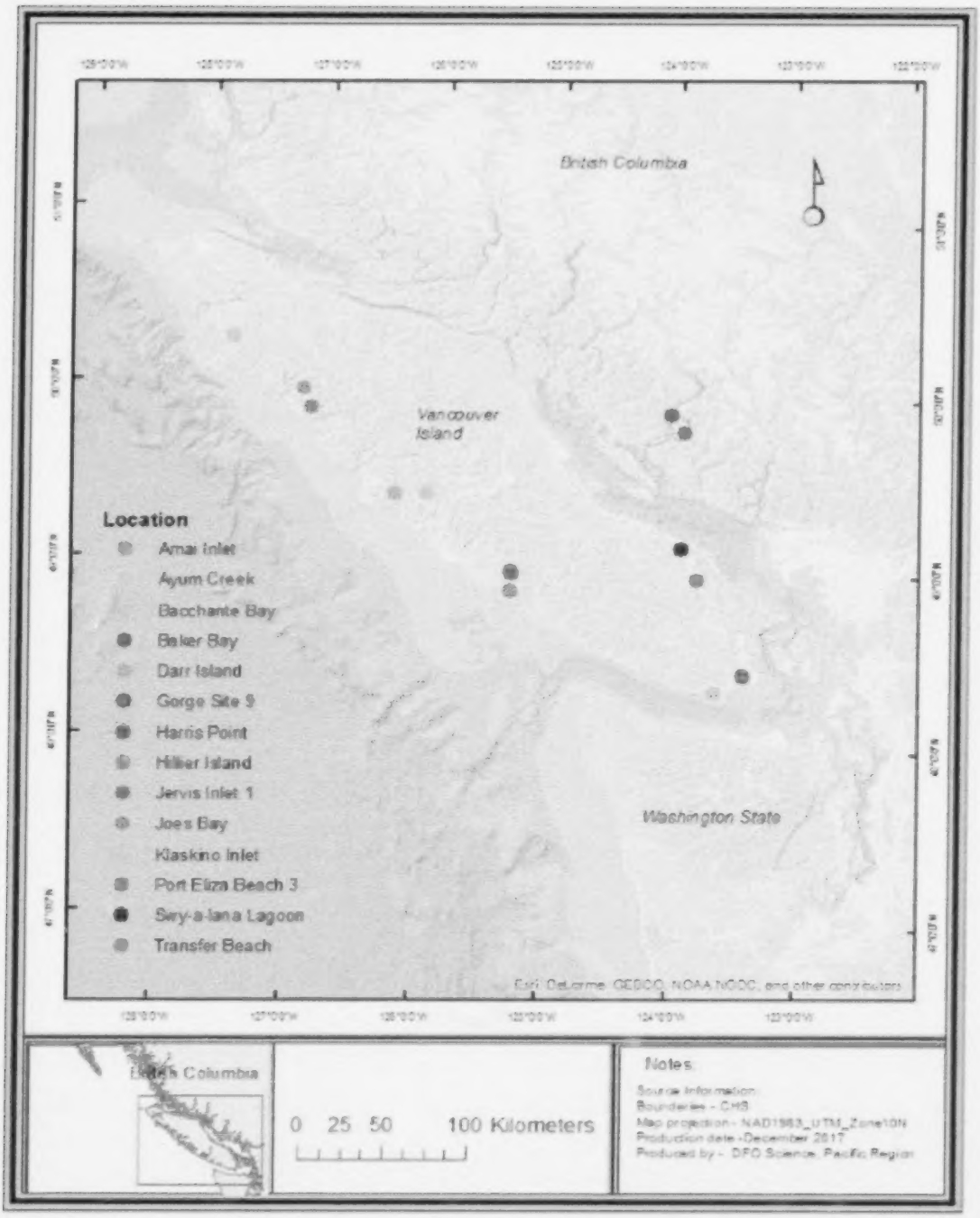


**Figure 1.** Olympia oyster index sites surveyed in British Columbia, 2009-2017.

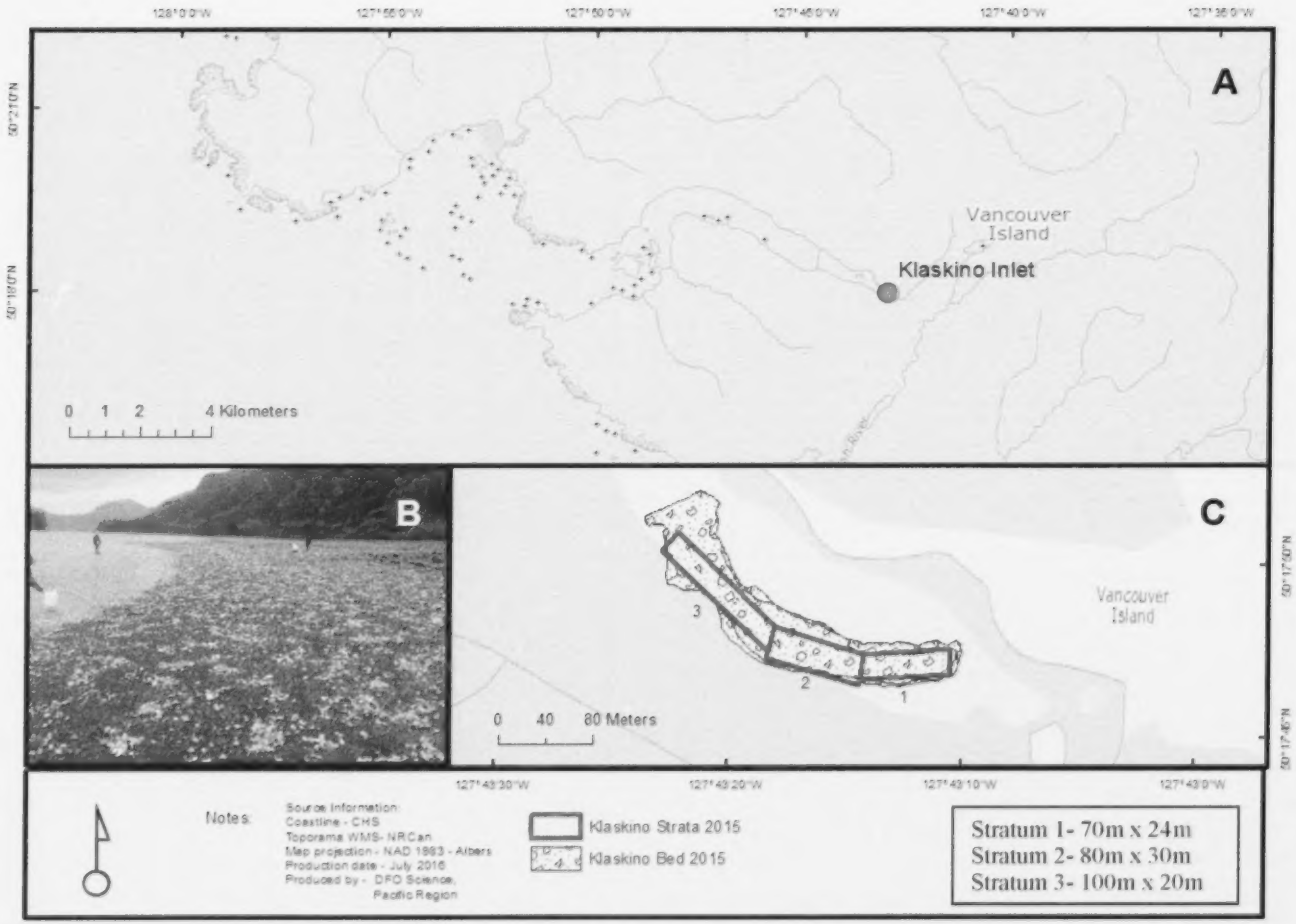


Figure 2. Location and strata layout for the Olympia oyster index site in Klaskino Inlet.

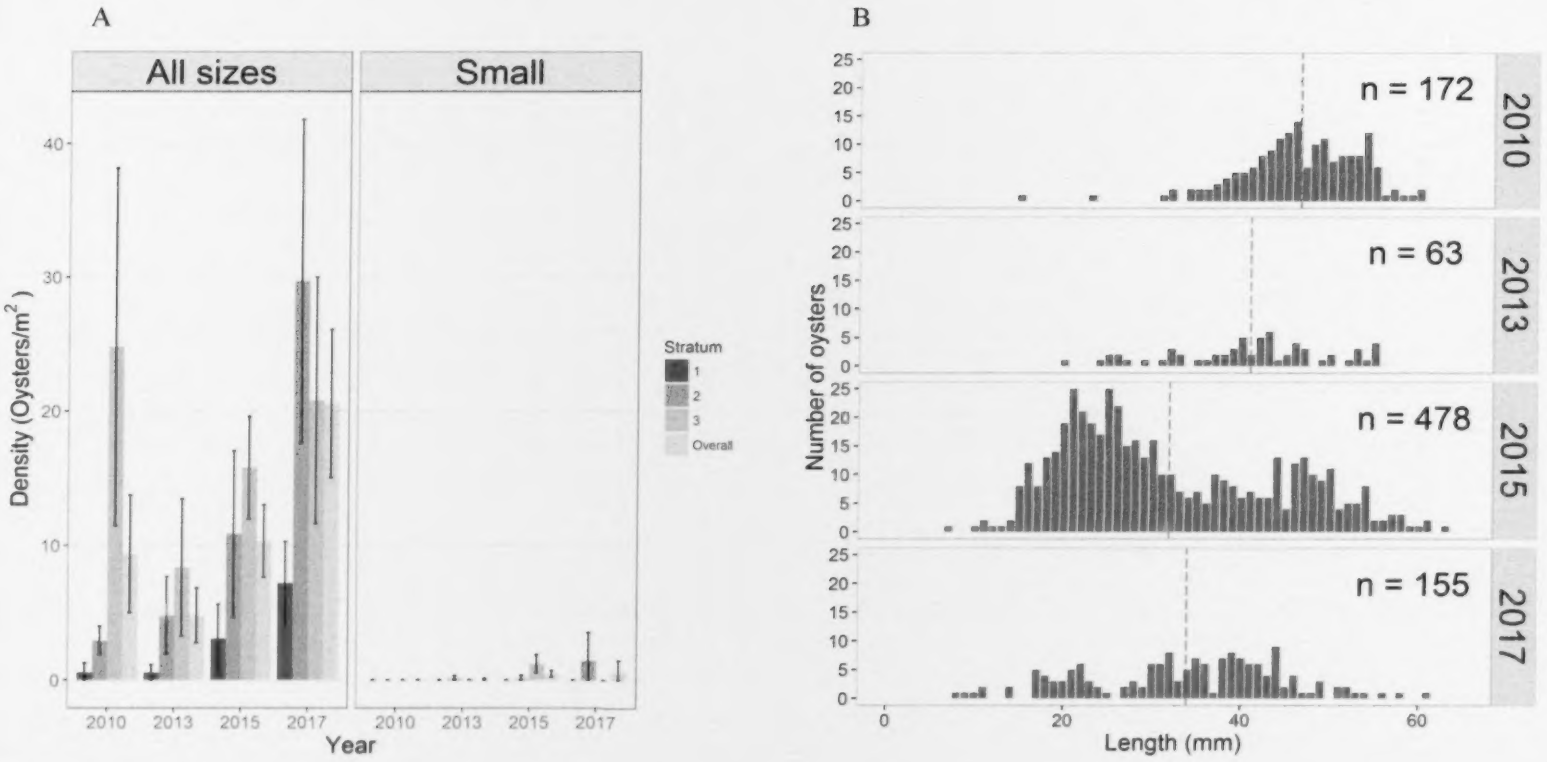


Figure 3. A) Klaskino Inlet Olympia oyster density (# m$^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Klaskino Inlet Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

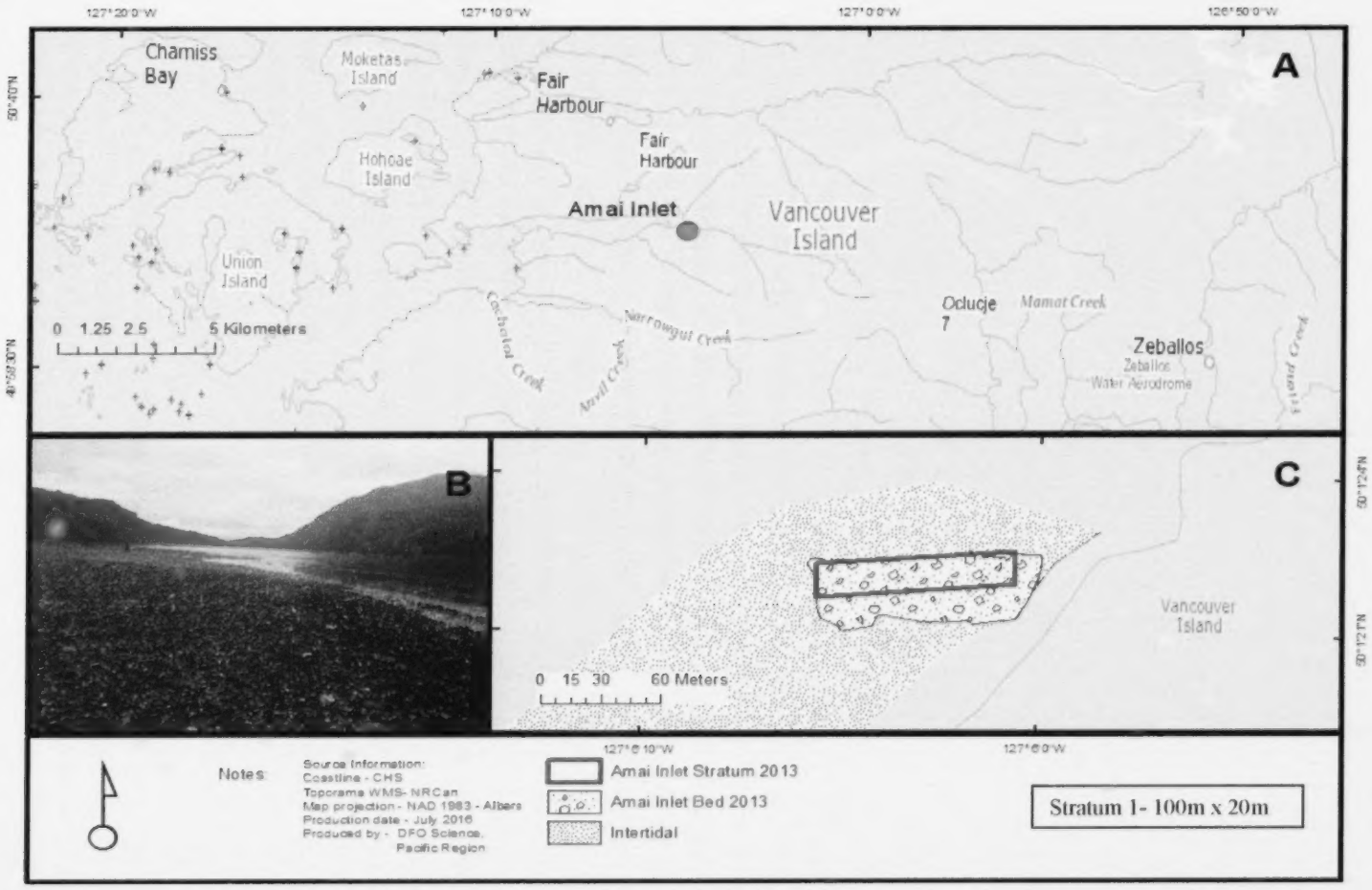


Figure 4. Location and stratum layout for the Olympia oyster index site in Amai Inlet.

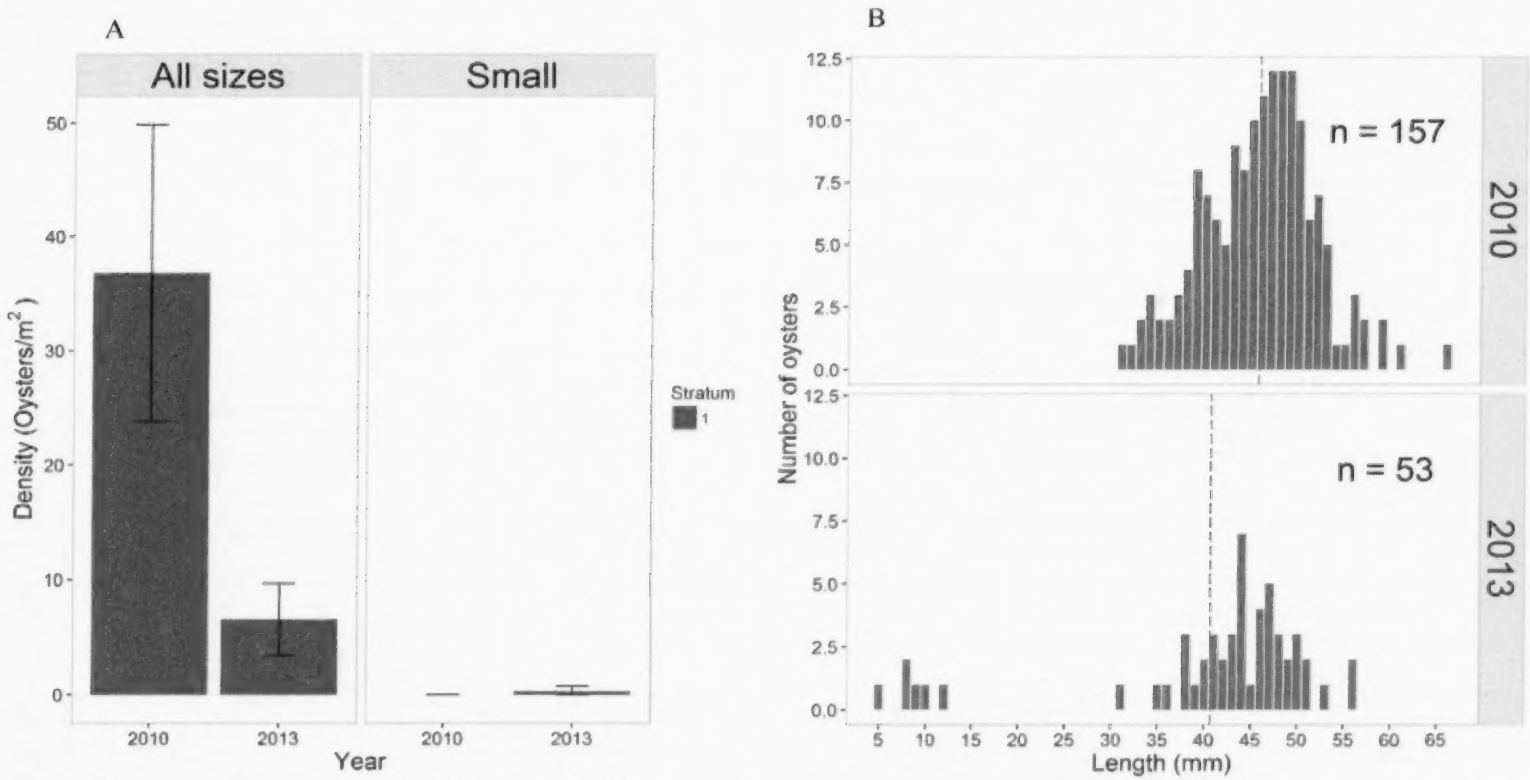


Figure 5. A) Amai Inlet Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Amai Inlet Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

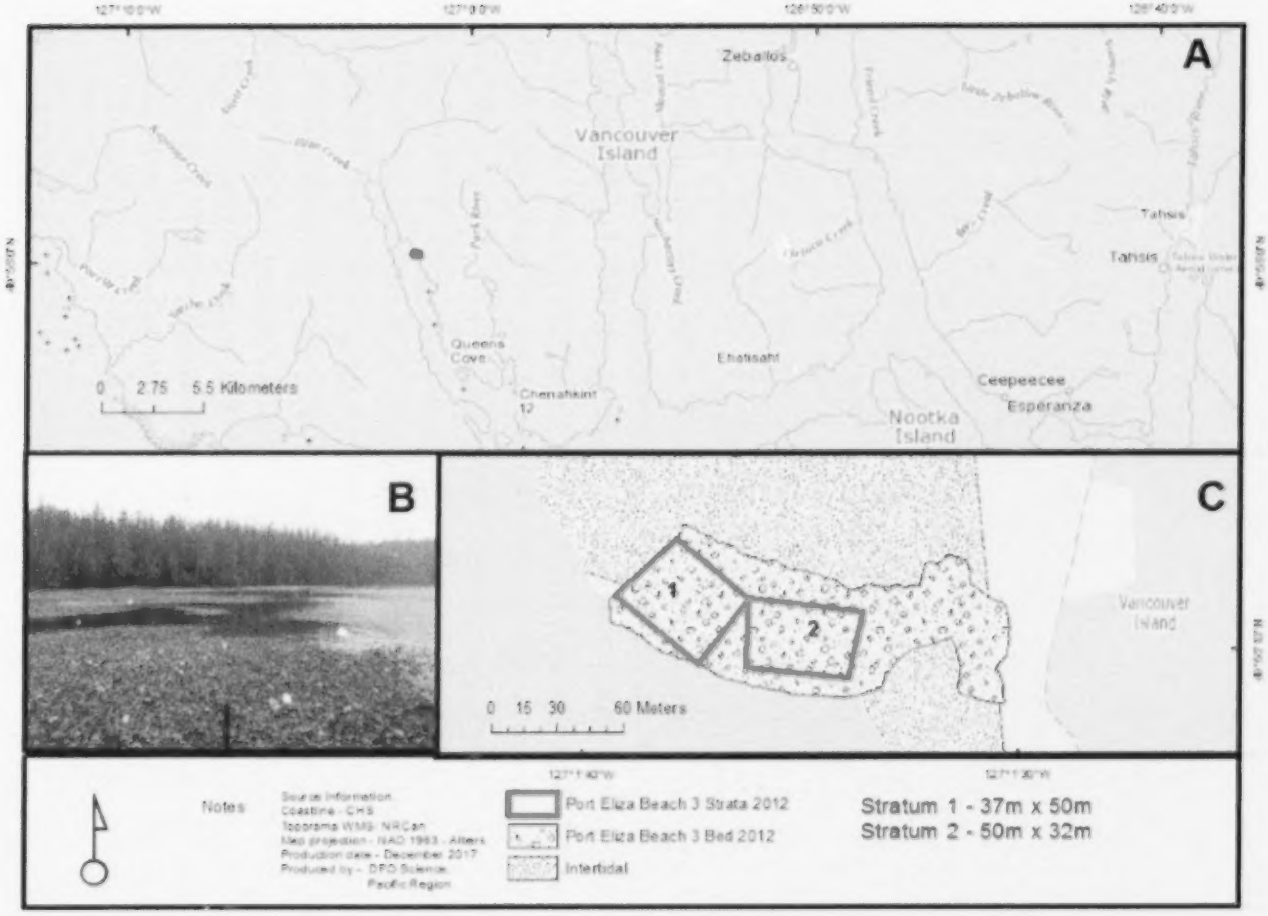


Figure 6. Location and strata layout for the Olympia oyster index site at Port Eliza Beach 3.

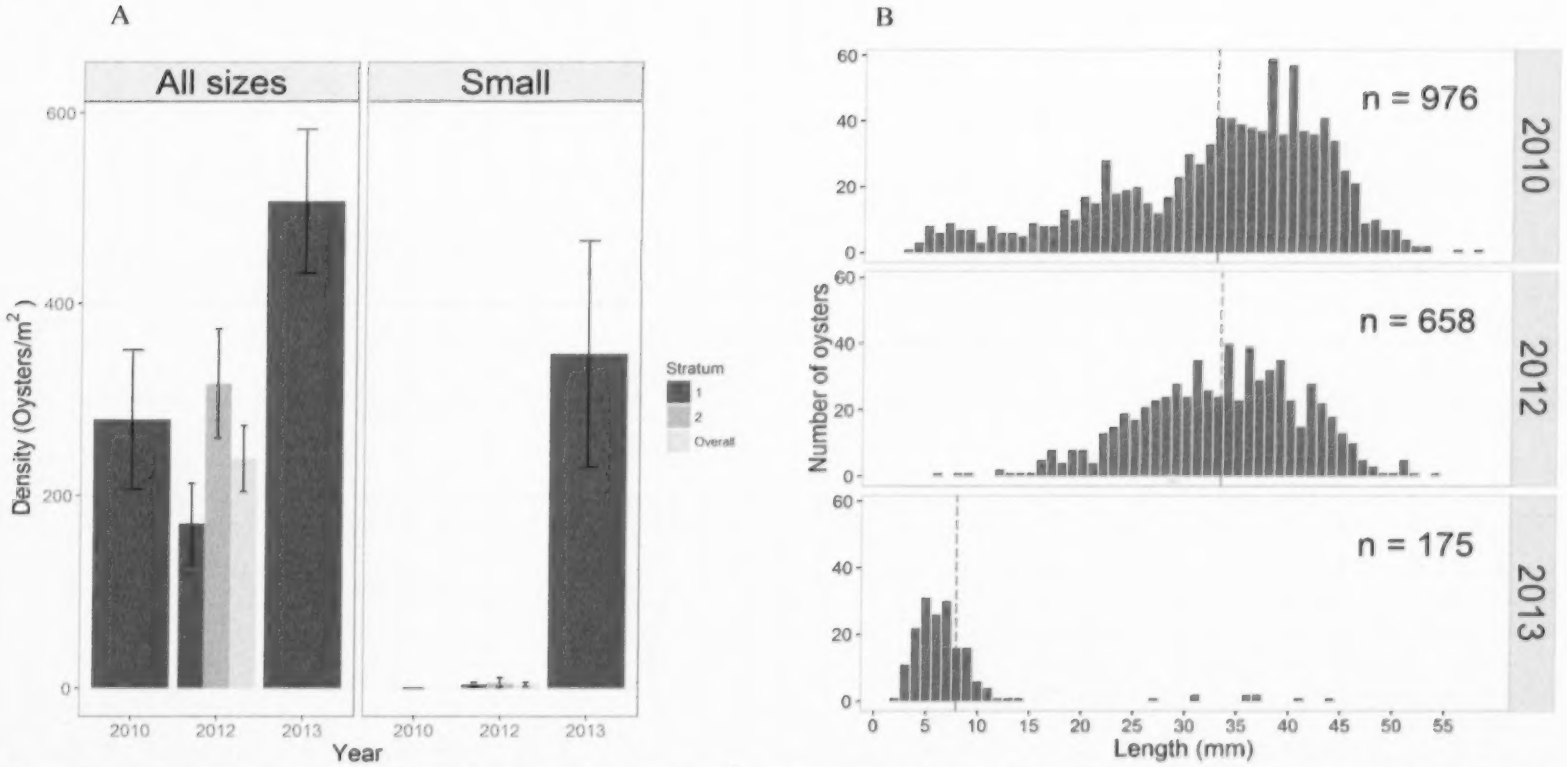


Figure 7. A) Port Eliza Beach #3 Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Port Eliza Beach 3 Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

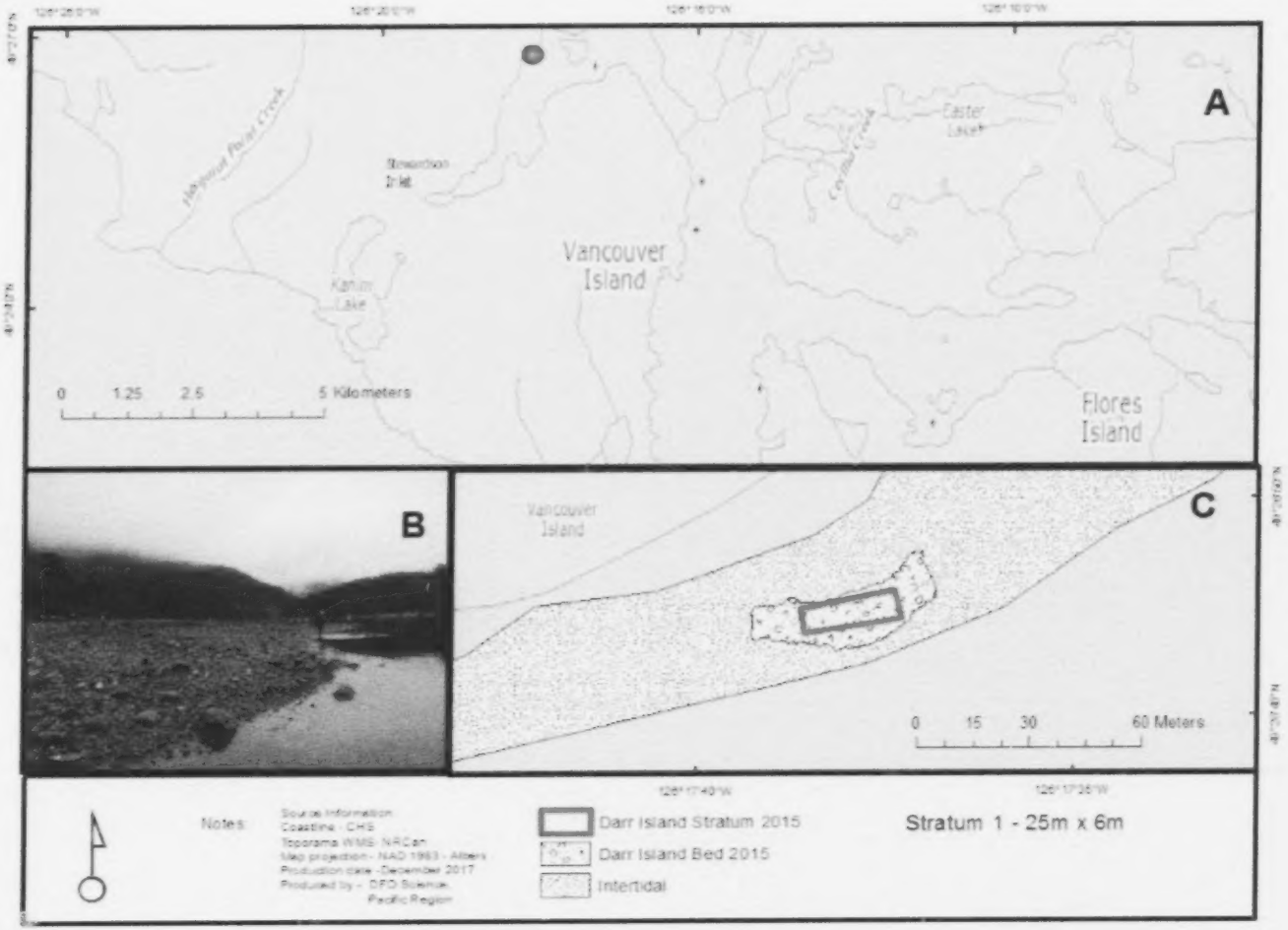


Figure 8. Location and stratum layout for the Olympia oyster index site in Darr Island.

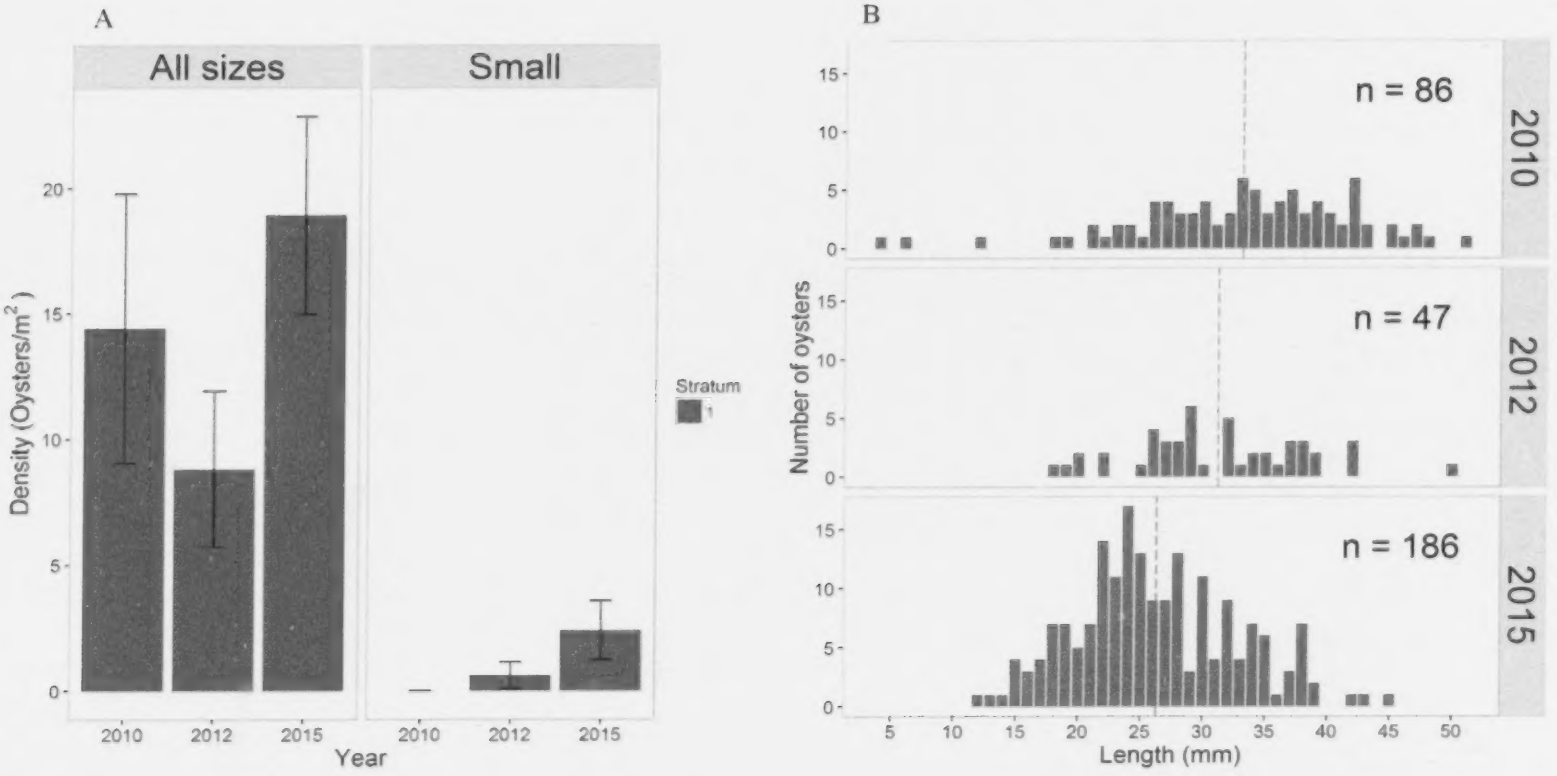


Figure 9. A) Darr Island Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Darr Island Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

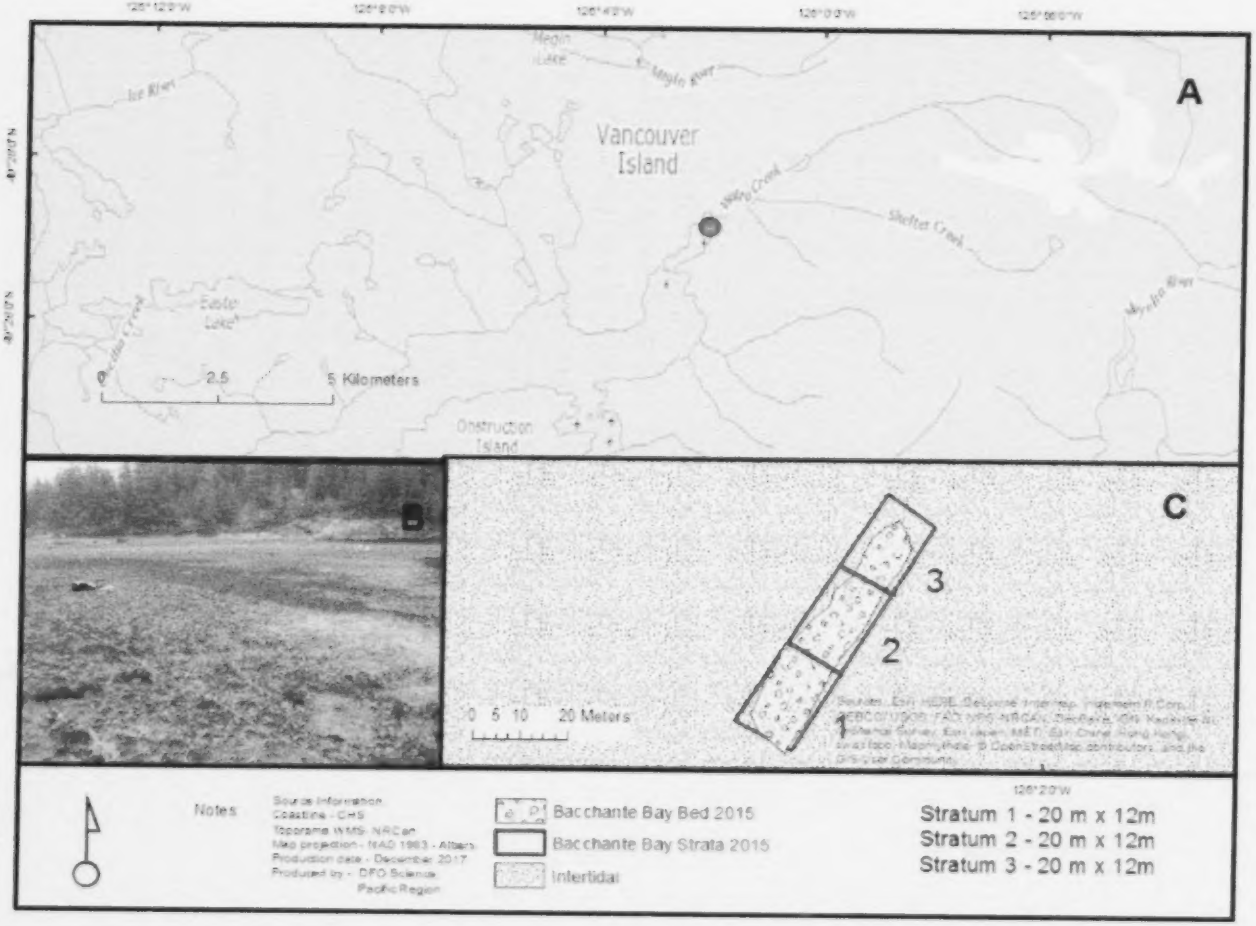


Figure 10. Location and strata layout for the Olympia oyster index site in Bacchante Bay.

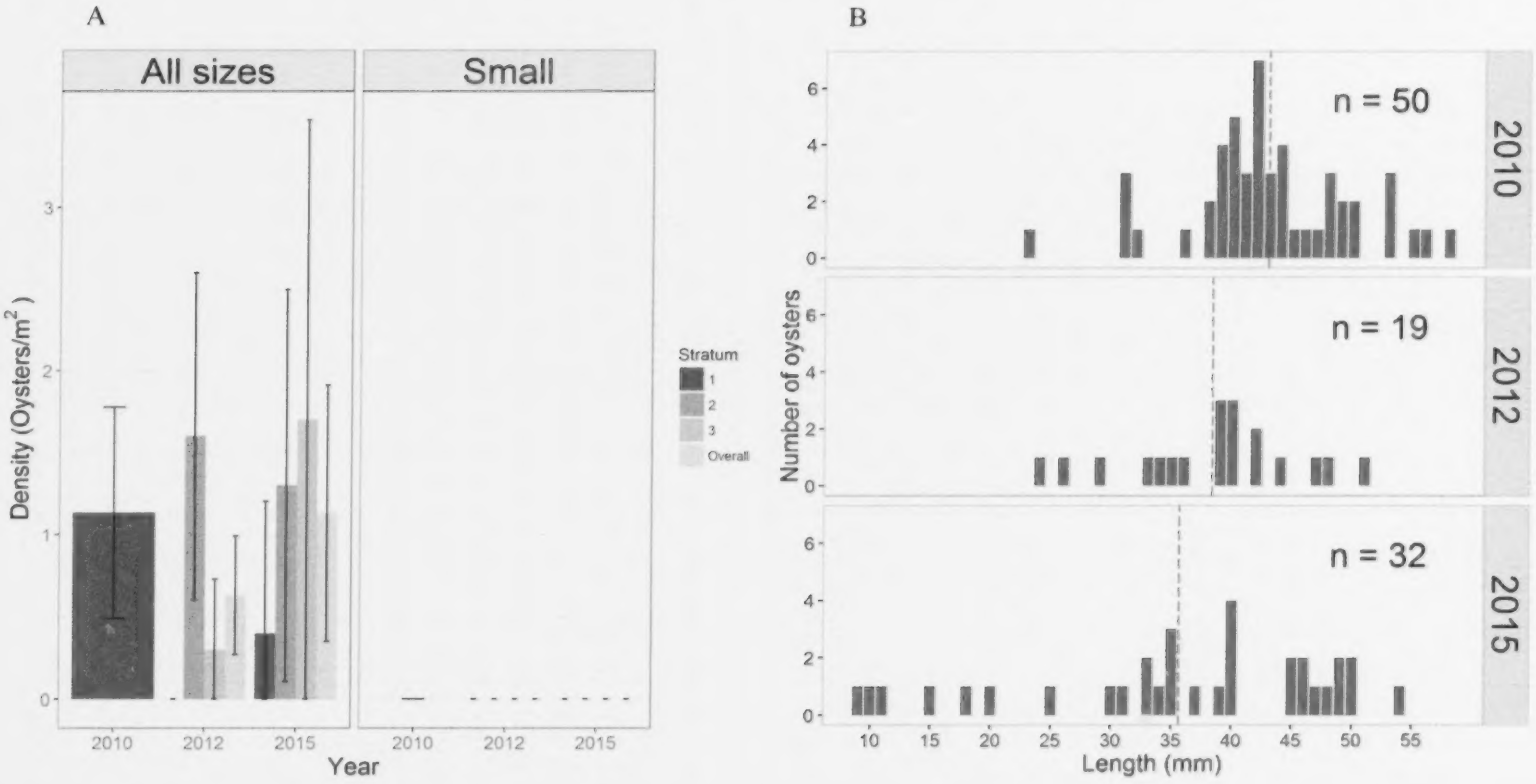


Figure 11. A) Bacchante Bay Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Bacchante Bay Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

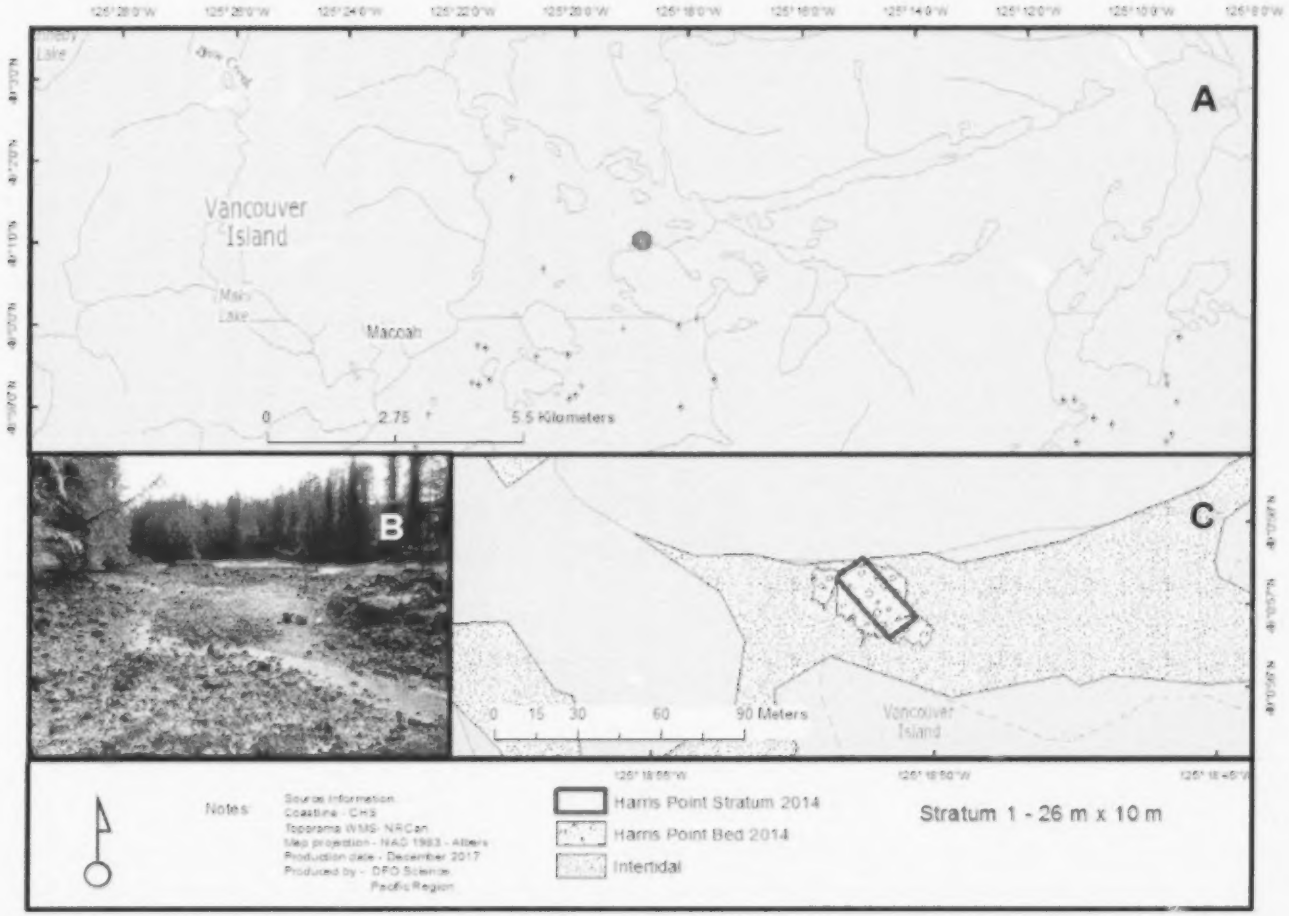


Figure 12. Location and stratum layout for the Olympia oyster index site at Harris Point.

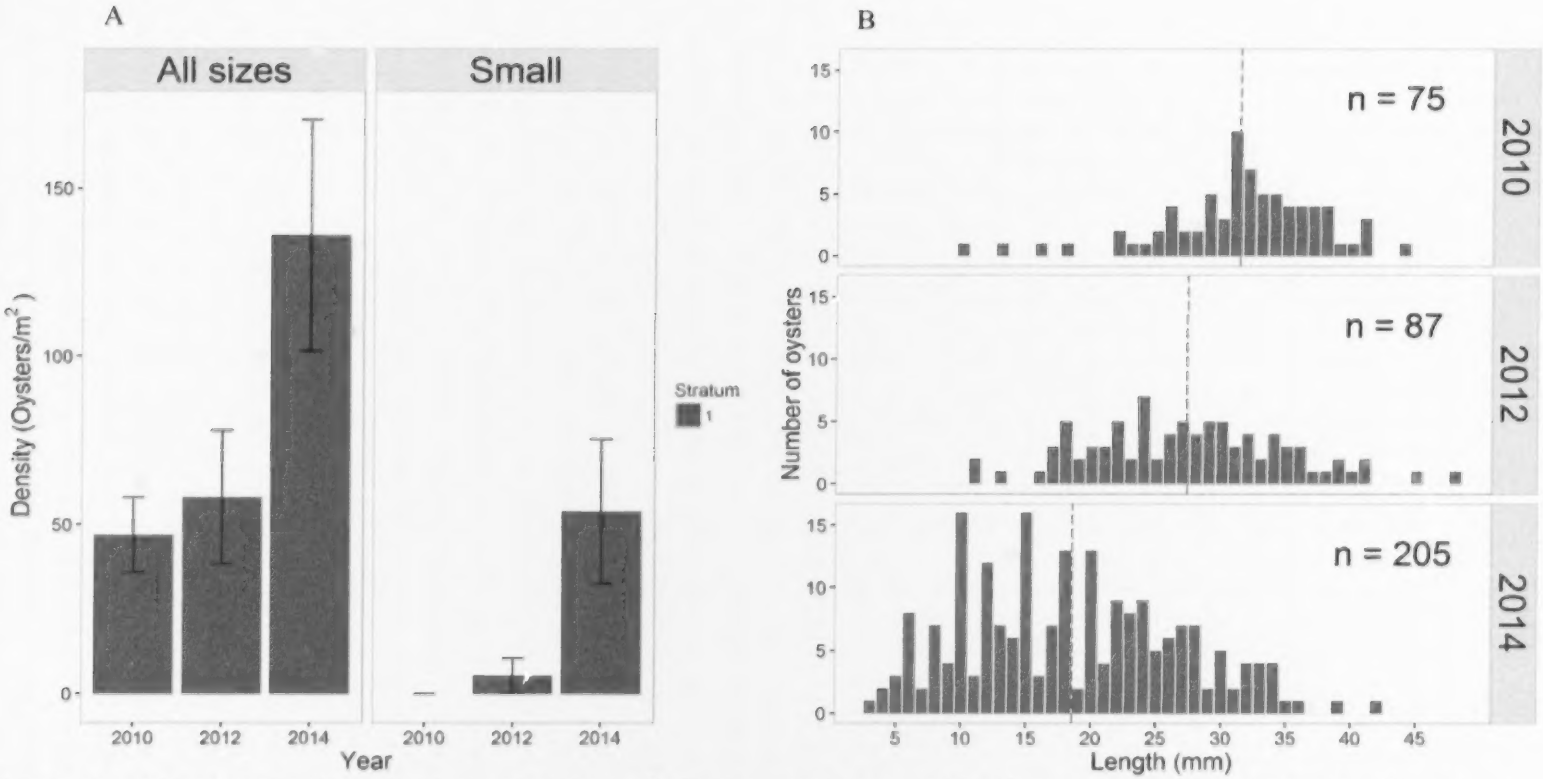


Figure 13. A) Harris Point Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B). Harris Point Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

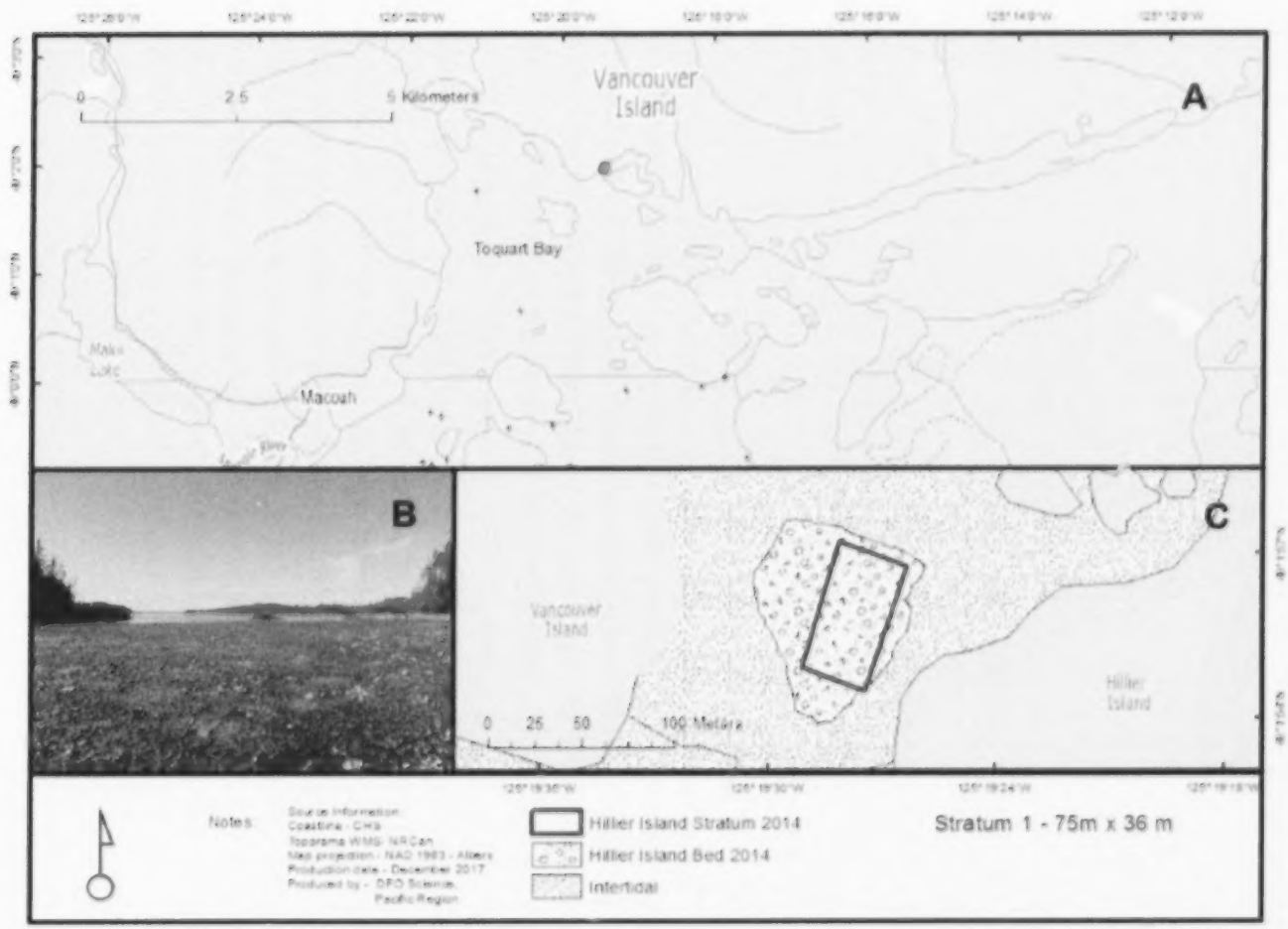


Figure 14. Location and stratum layout for the Olympia oyster index site at Hillier Island.

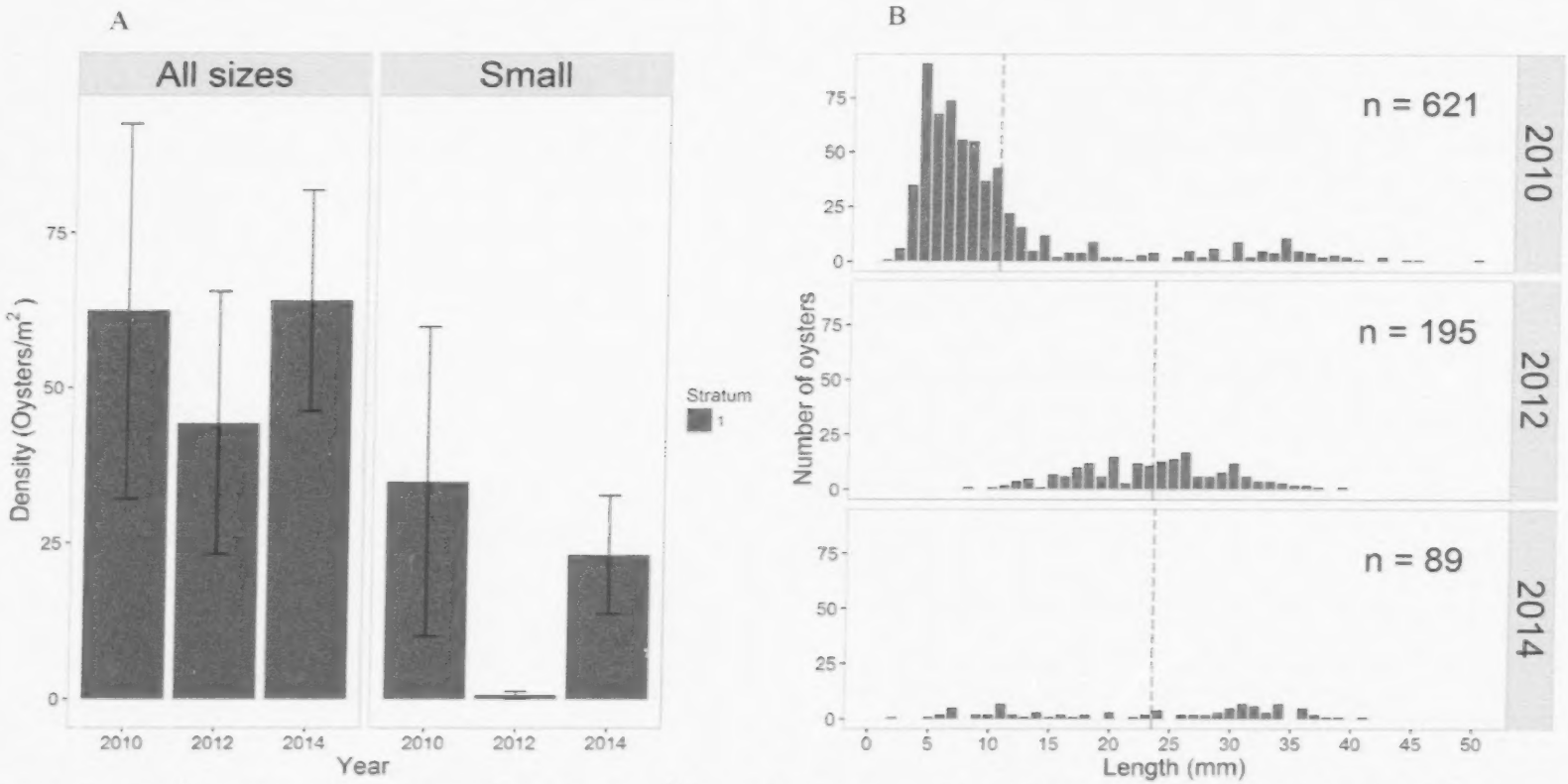


Figure 15. A) Hillier Island Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Hillier Island Olympia oyster size frequency (mm). Red dotted lines are mean length (mm)

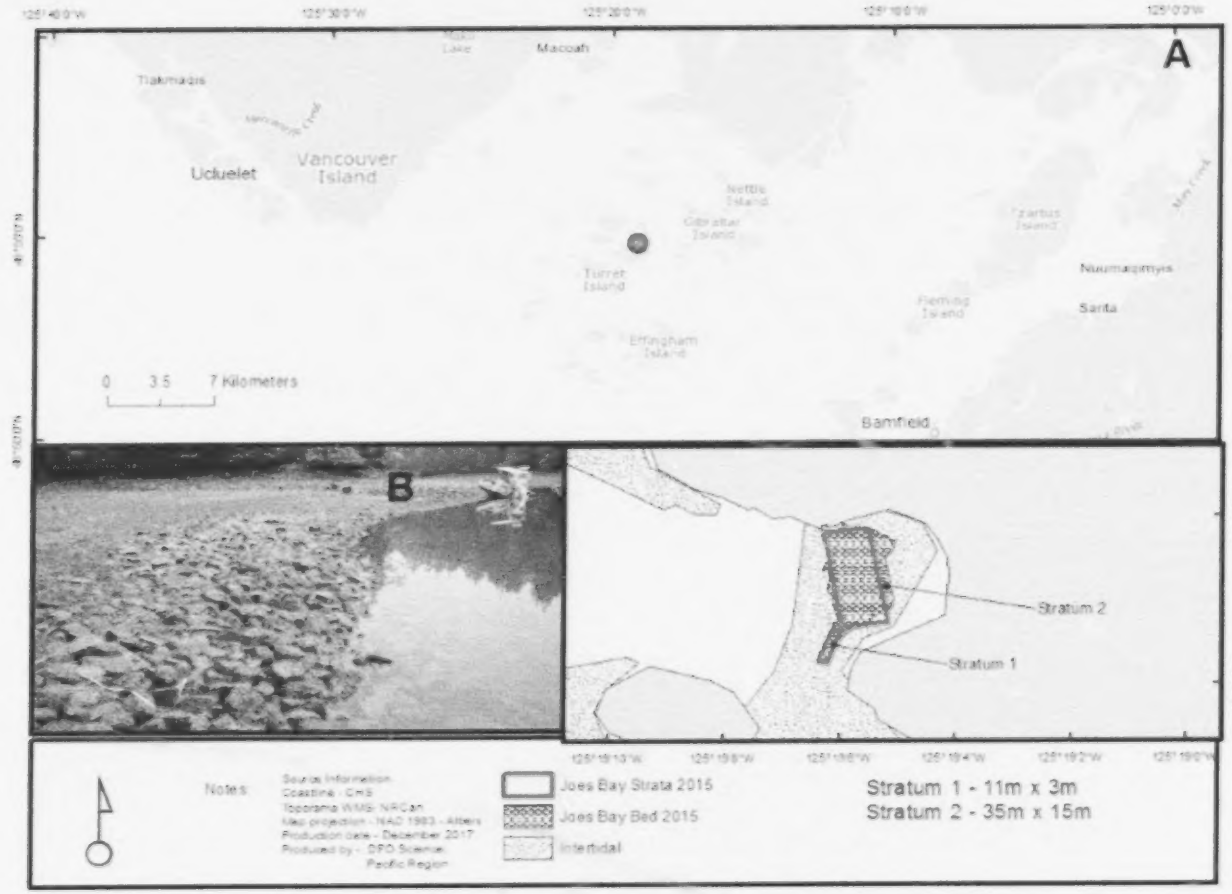


Figure 16. Location and strata layout for the Olympia oyster index site in Joes Bay.

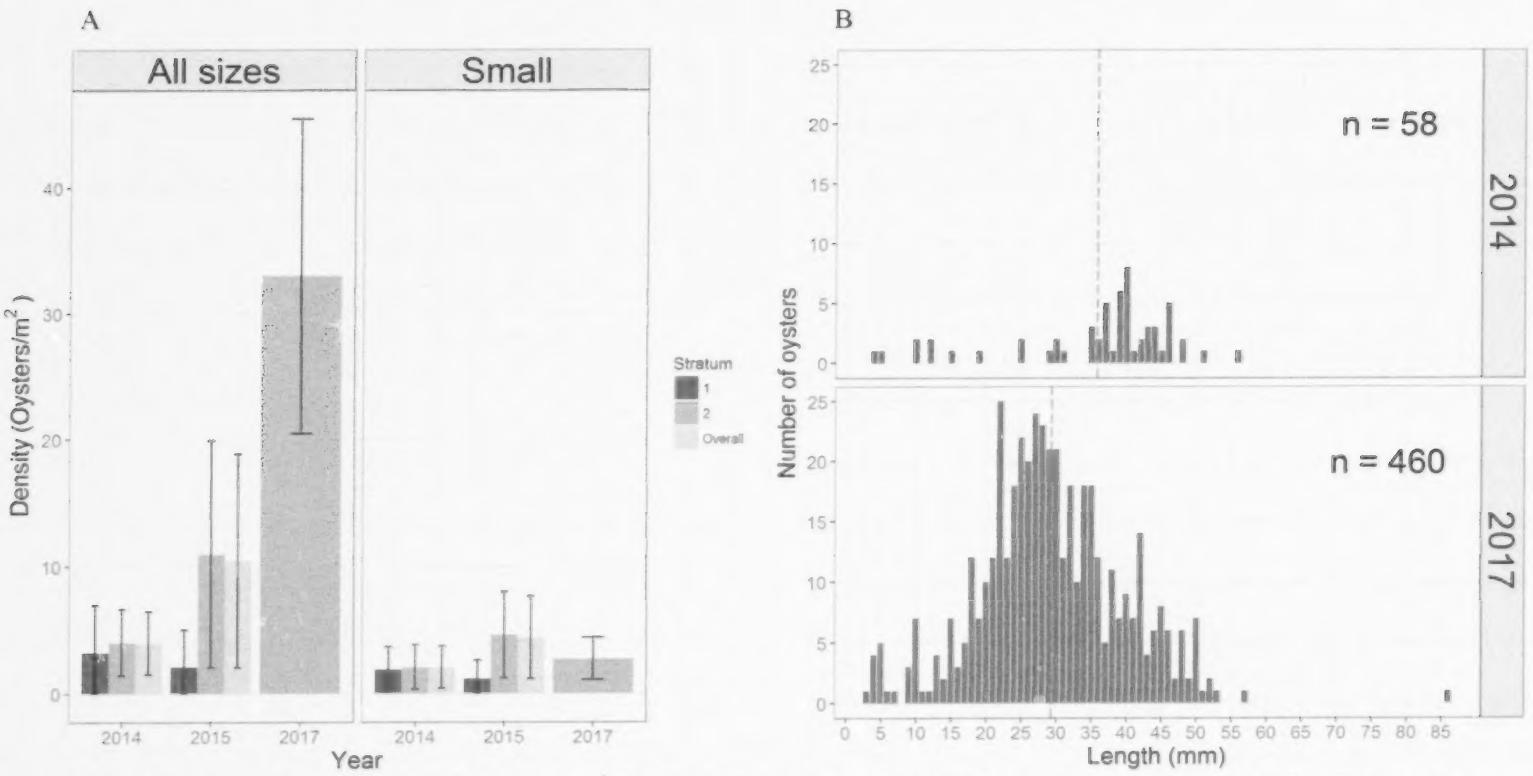


Figure 17. A) Joes Bay Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm). B) Joes Bay Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

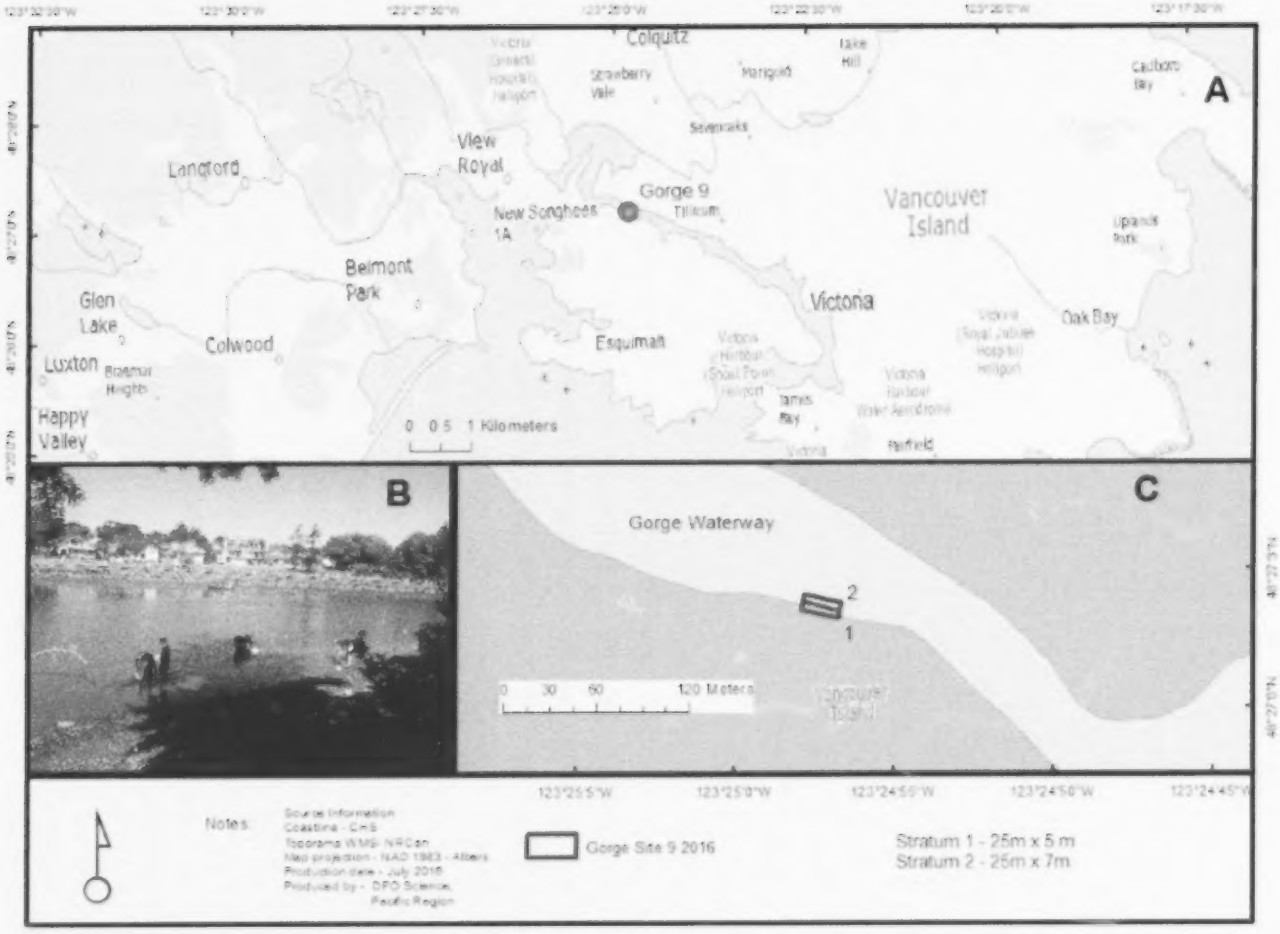


Figure 18. Location and strata layout for the Olympia oyster index site at Gorge Site 9.

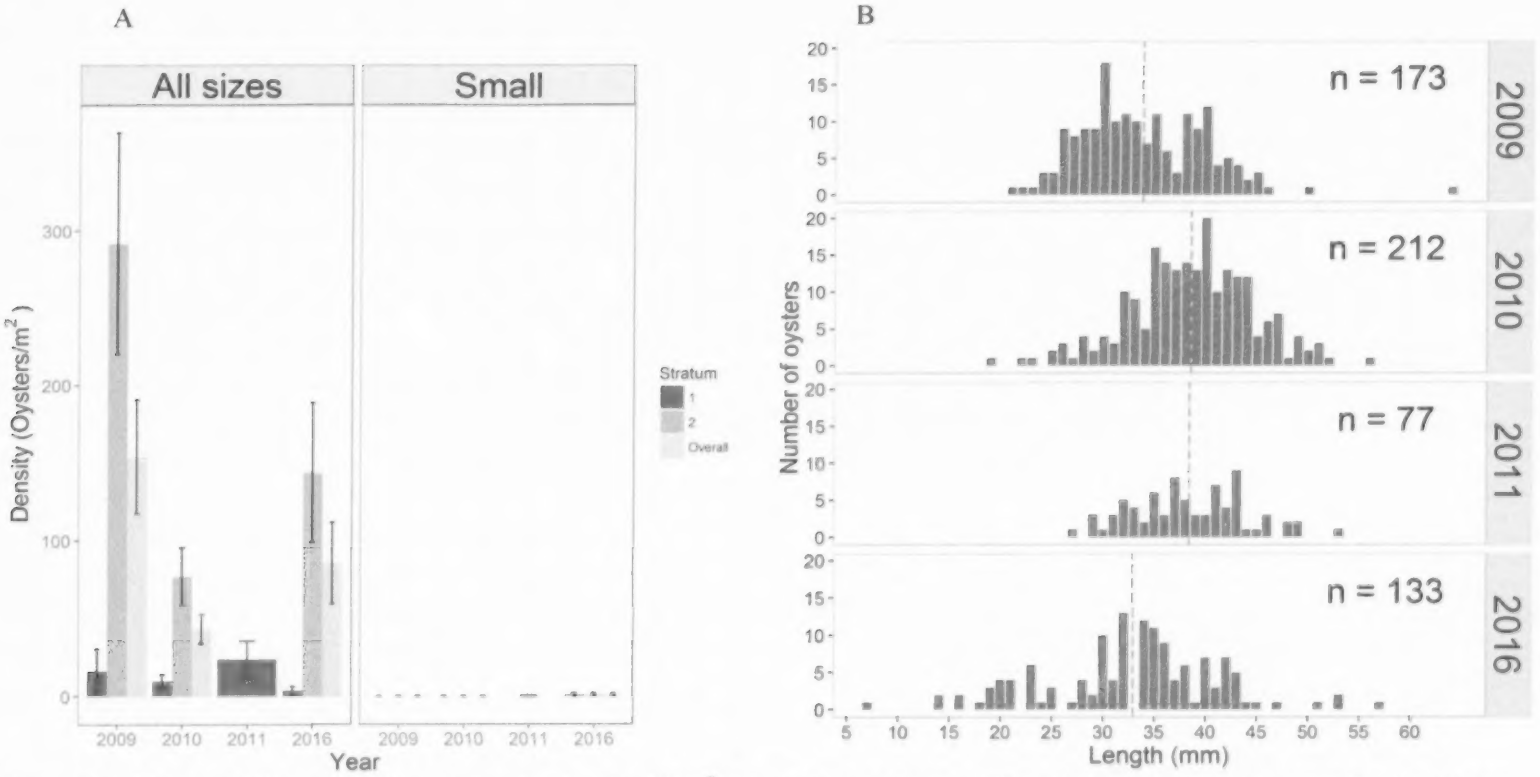


Figure 19. A) Gorge Waterway Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Gorge Waterway Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

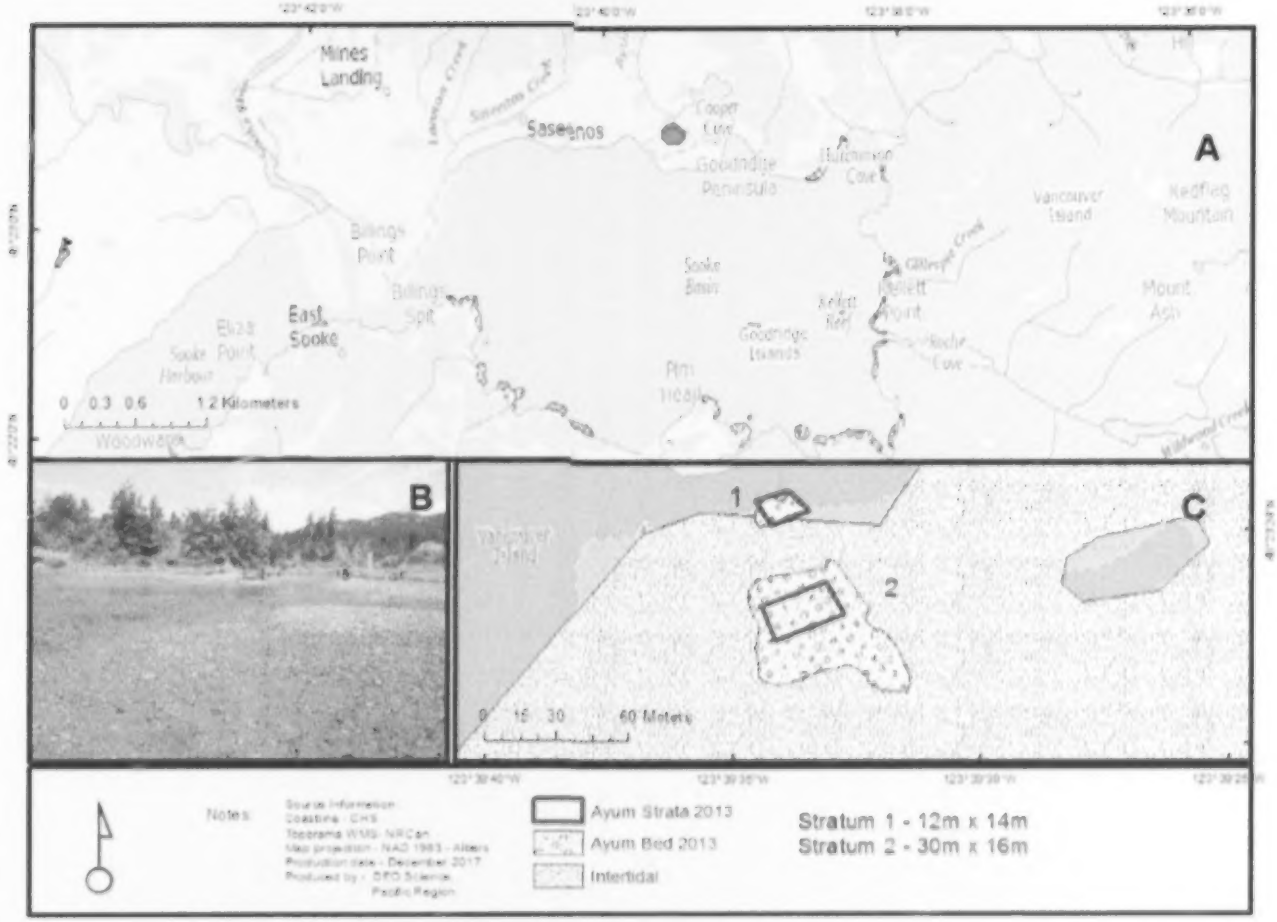


Figure 20. Location and strata layout for the Olympia oyster index site at Ayum Creek.

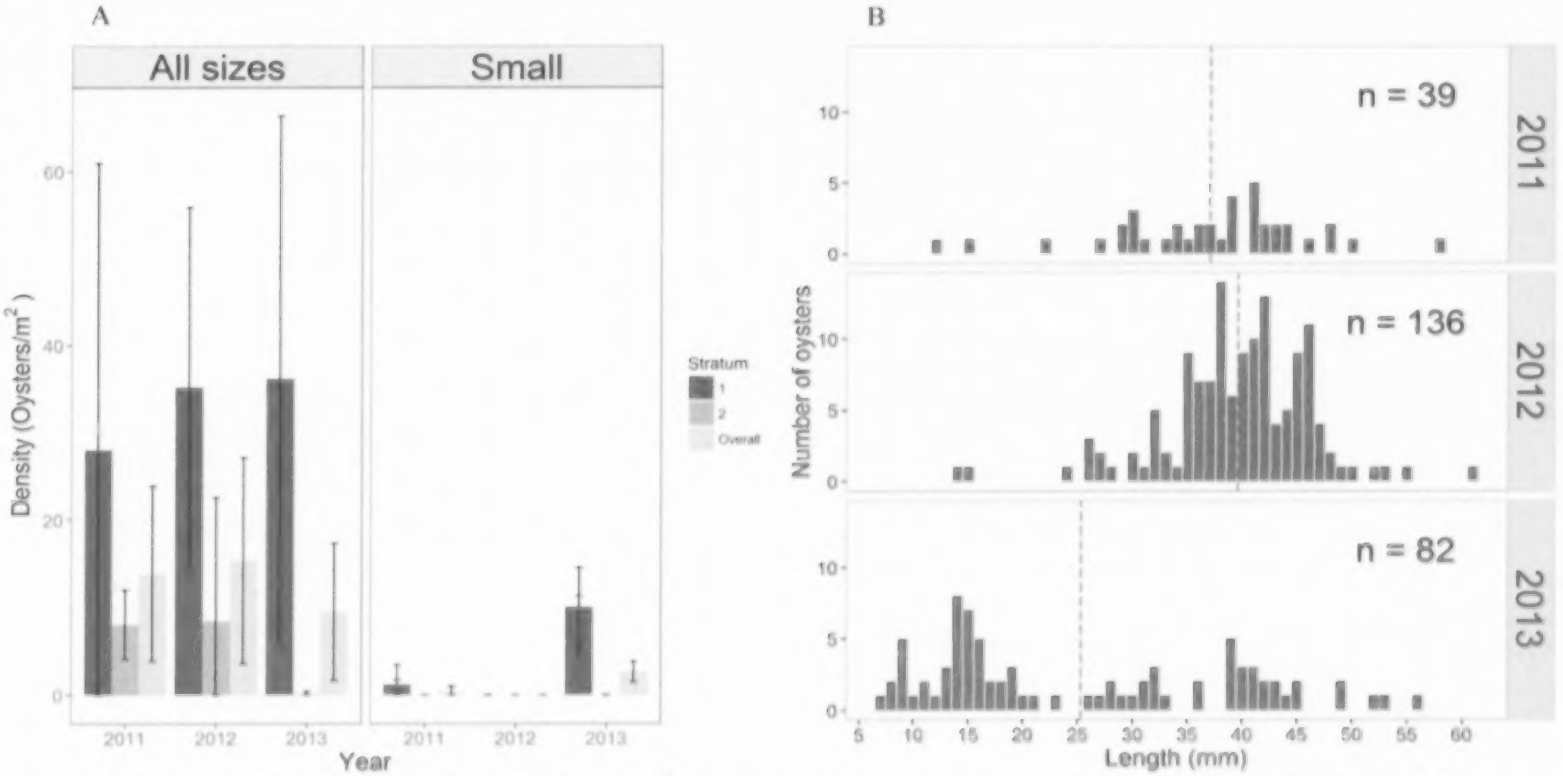


Figure 21. A) Ayum Creek Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Ayum Creek Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

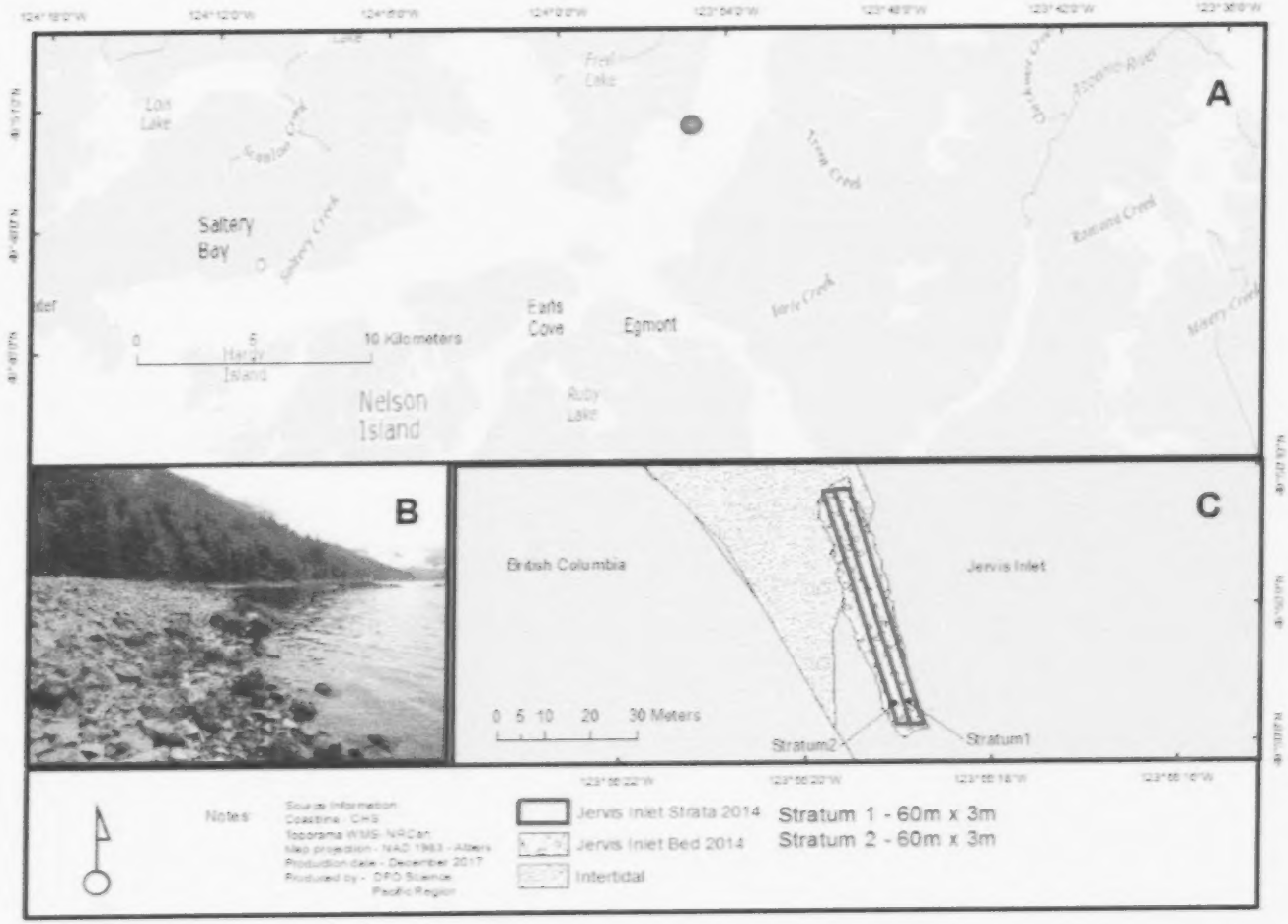


Figure 22. Location and strata layout for the Olympia oyster index site in Jervis Inlet.

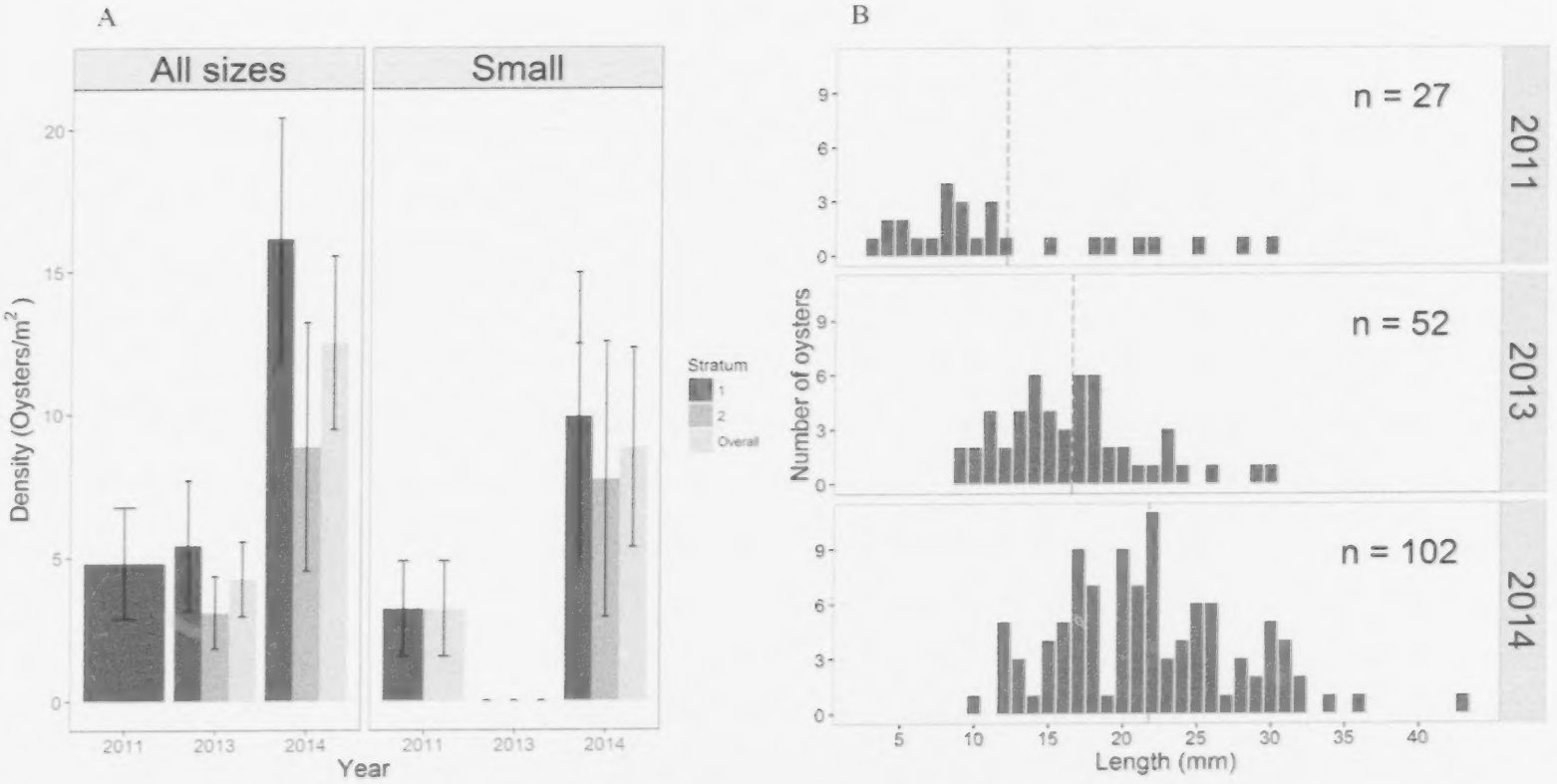


Figure 23. A) Jervis Inlet Olympia oyster density (# m$^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Jervis Inlet Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

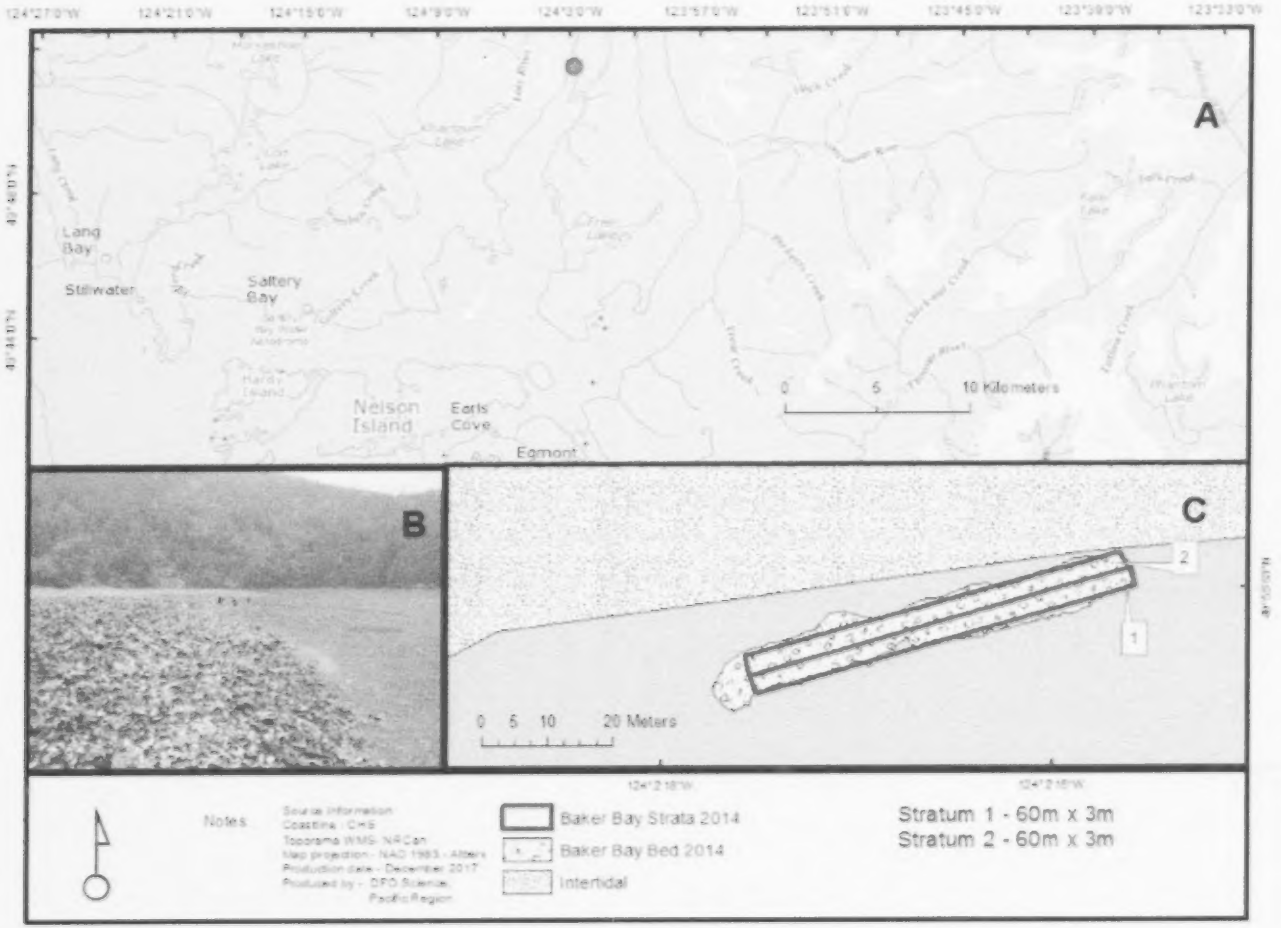


Figure 24. Location and strata layout for the Olympia oyster index site in Baker Bay.

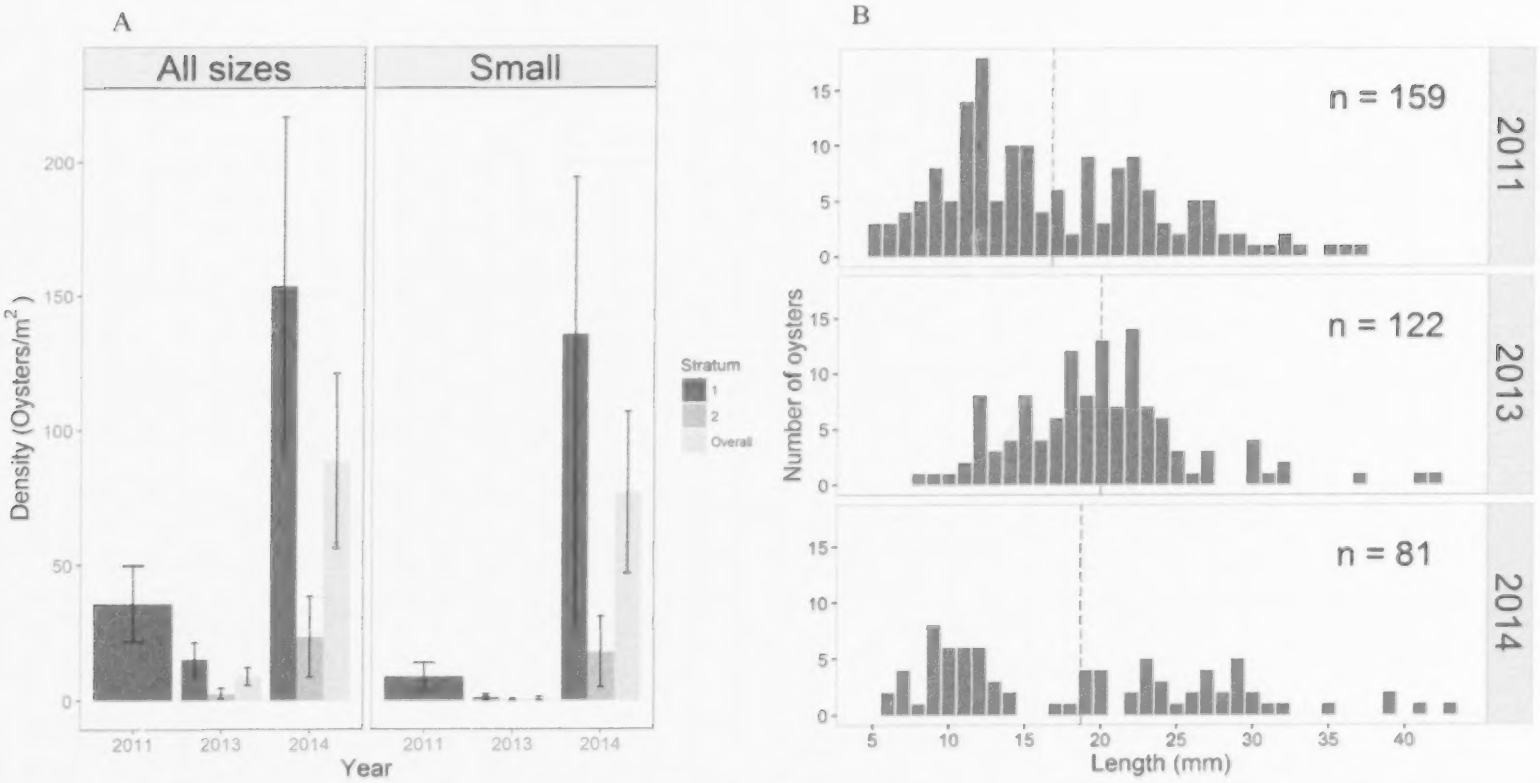


Figure 25. A) Baker Bay Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Baker Bay Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

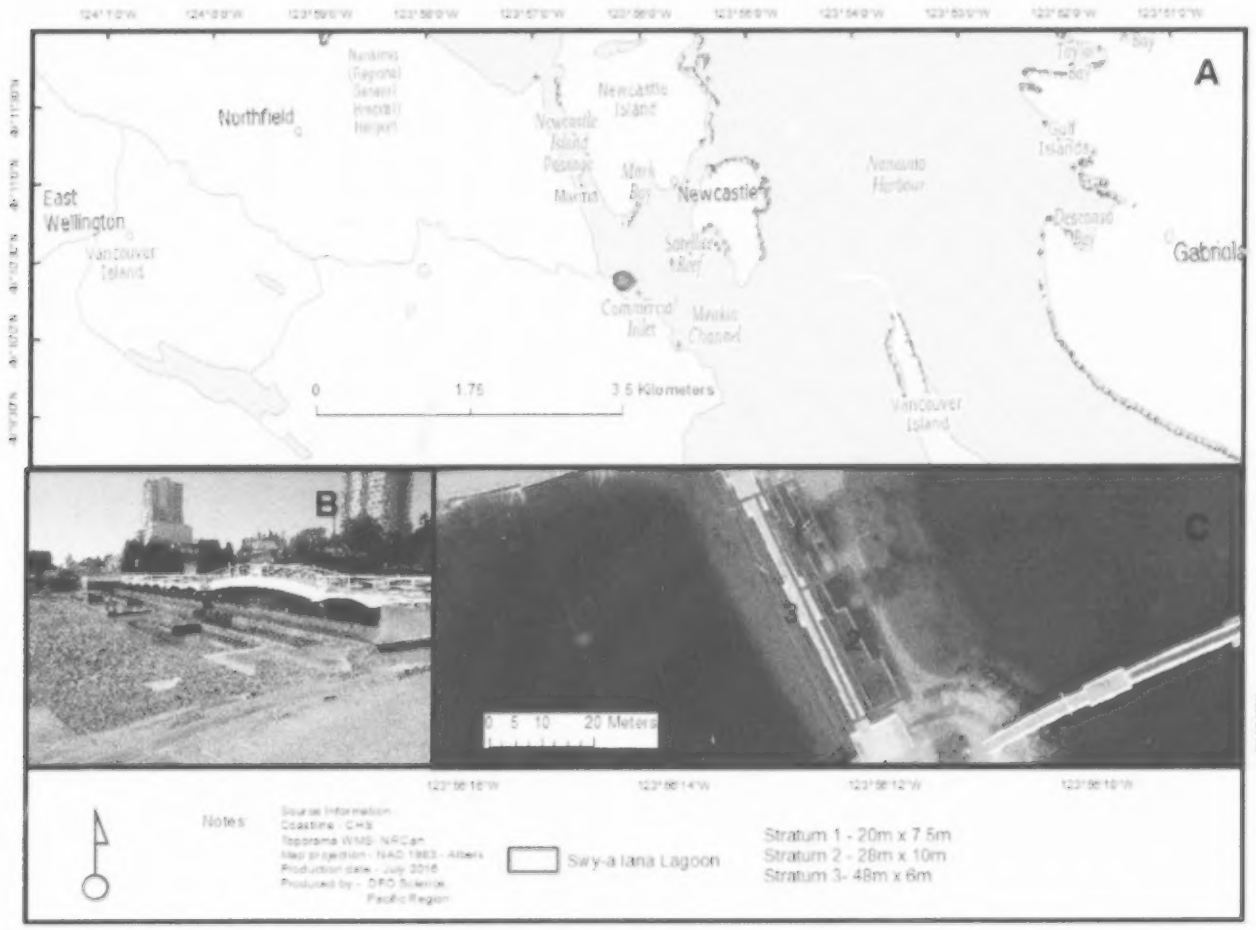


Figure 26. Location and strata layout for the Olympia oyster index site in Swy-a-lana Lagoon.

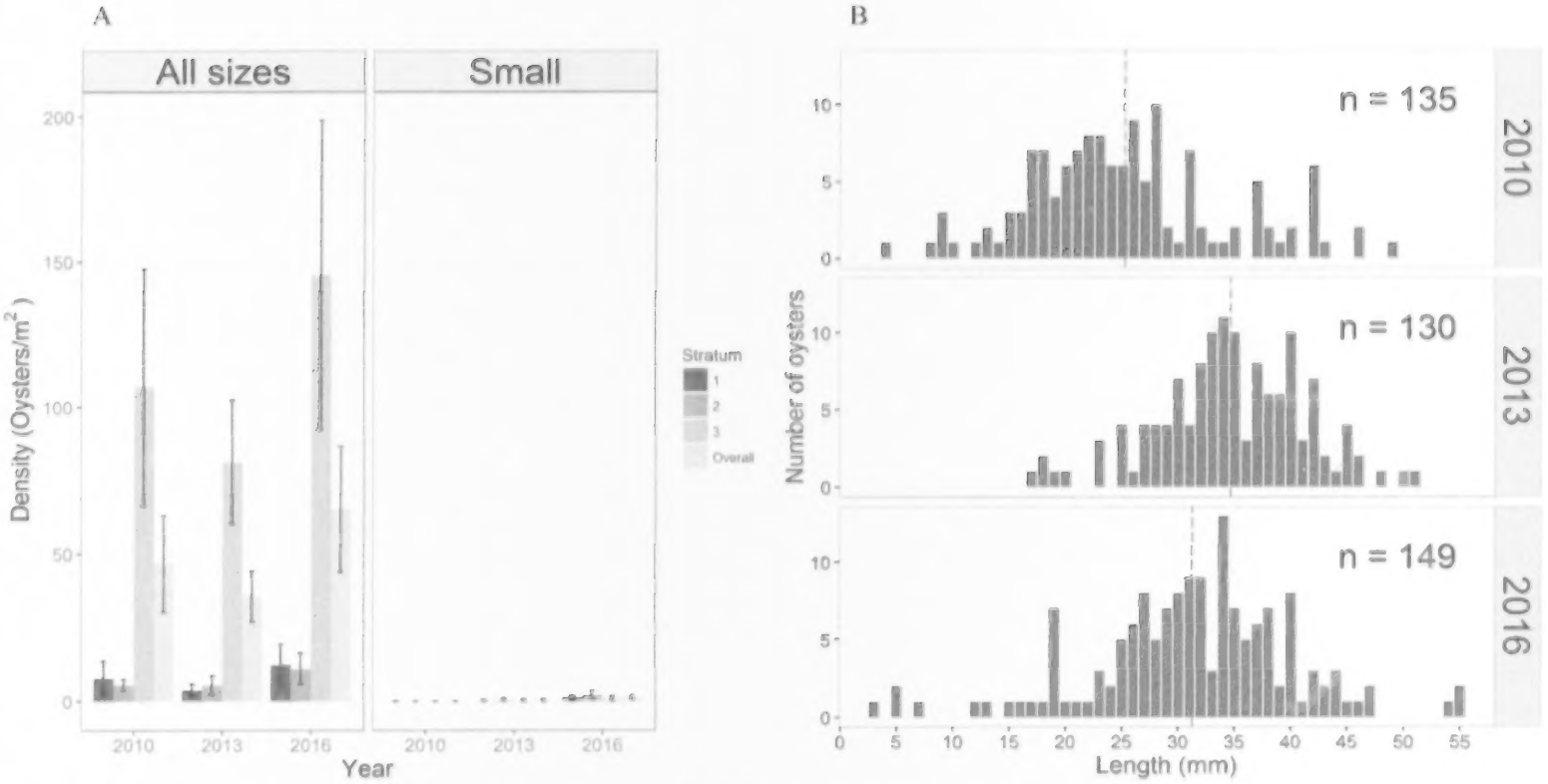


Figure 27. A) Swy-a-lana Lagoon Olympia oyster density(# $m^{-2}$) by stratum and year . The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Swy-a-lana Lagoon Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

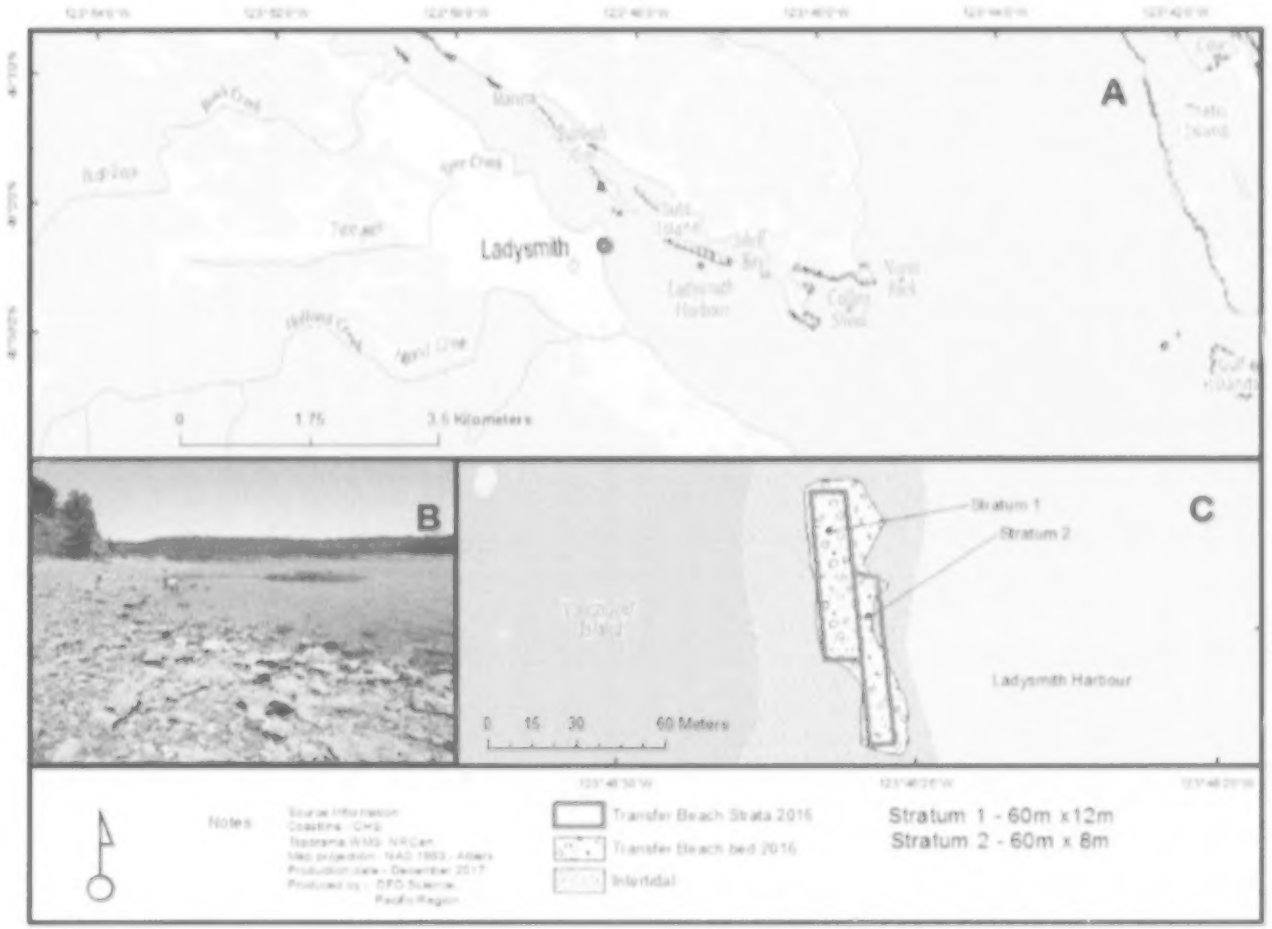


Figure 28. Location and strata layout for the Olympia oyster index site at Transfer Beach.

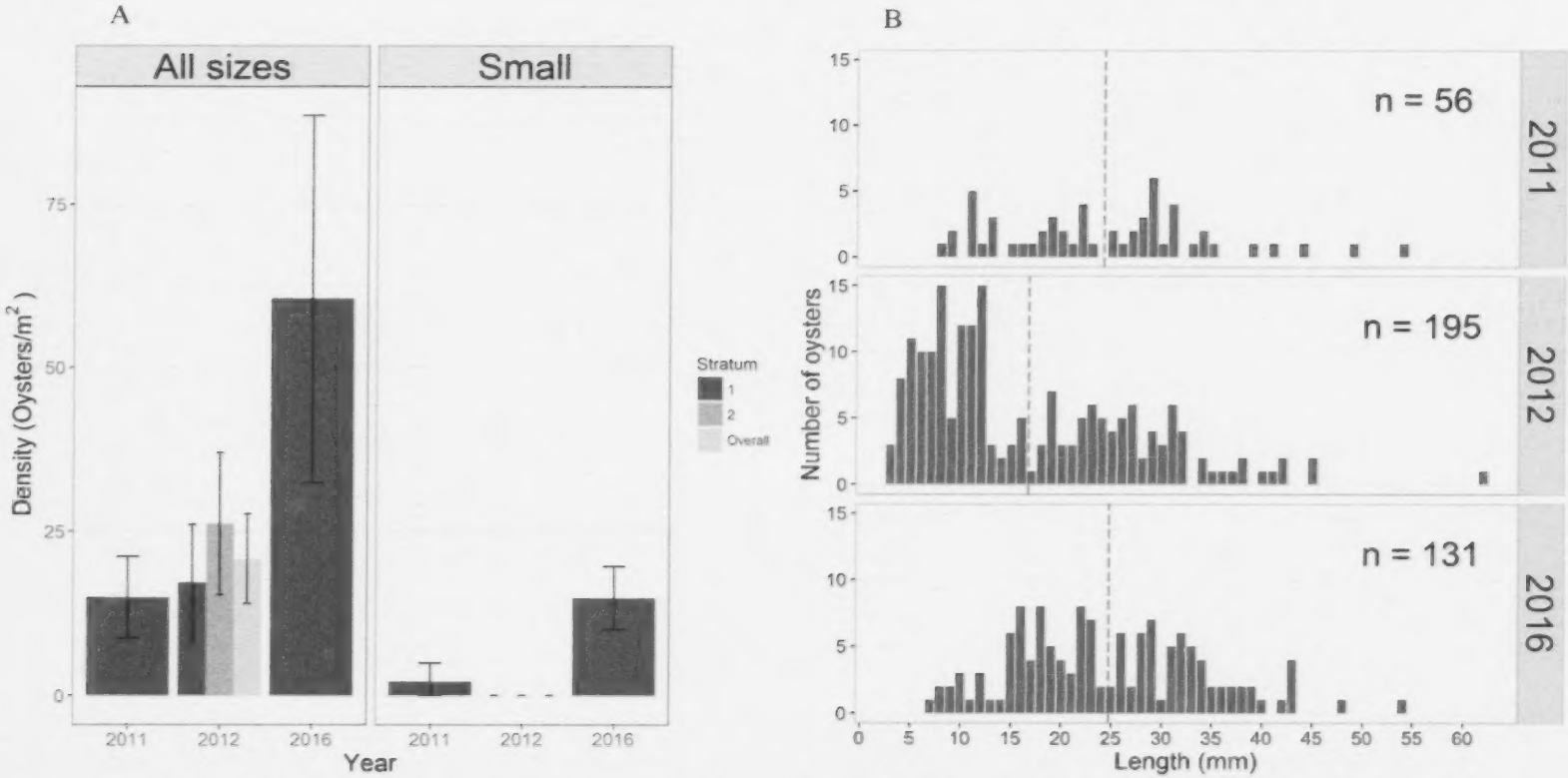


Figure 29. A) Transfer Beach Olympia oyster density (# $m^{-2}$) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Transfer Beach Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

# Appendices

**Appendix 1. R code used for setting Two-Stage survey designs.**

## Cluster_Analysis_R_Oly_Final_17Oct03.R

Biggm

Tue Dec 05 17:19:10 2017

```
#Important Note Jan 24, 2016
# When the data is brought in for this code it is Transformed to m2, so the total numbe
r of oyster is multiplied but the number of quadrats either 4 or 16
# Then when the population estimate is calculated it is the m2 estimate that is being u
sed.  This is different from the
# code label est at quad size and that codes population estimate can just be multiplied
by 4 or 16 to get pop estimate both codes
# were done to for comparison so I could what the calculated error estimate were with
each method.

## Date Modified Jan 21, 2016
## This code was created by Tammy Norgard from an initial code created by Carl S
wartz and has a loop from Matte
## This code takes the file extracted from the database query call allkeyloc and mak
es all changes in the code.
#So if there are changes to the database we can just rerun the code
#A second file is needed to be made in excel that has all the strata area and the survey
names created in this code called allkeylocnames
#(this would be great if it could be made in this code)
#Run this hole file and it will produce 3 CSV files (Large&small oly analysis, large oly a
nalysis, small oly analysis)

########## Initial cleanup ##########
rm(list=ls(all=TRUE))
while("data.sub" %in% search()) detach(data.sub)   #if script has previsously crashe
d, data.sub will still be attached.


### this r code will take the data file that come out of the database query called oyst
er_datacluster and reorganize it for cluster analysis.

library(doBy)
```

```
## Warning: package 'doBy' was built under R version 3.2.5

library(survey)

## Loading required package: grid

## Loading required package: Matrix

## Loading required package: survival

## Warning: package 'survival' was built under R version 3.2.5

##
## Attaching package: 'survey'

## The following object is masked from 'package:graphics':
##
##    dotchart

library(plyr)

## Warning: package 'plyr' was built under R version 3.2.5

#library(nlme)
#library(pastecs)
#library(ggplot2)
#library(lmerTest)
#library(lsmeans)
#library(plyr)

#################################################################
#LARGE and Small Oly counts ######################################

#brings in data
name.strat <- read.csv("allkeylocnames.csv", header=TRUE)
head (name.strat)

##  Source H1_Key                        Description
## 1      O  1506          Klaskino Inlet, Head of, N. Side
## 2      O  1506          Klaskino Inlet, Head of, N. Side
## 3      O  1506          Klaskino Inlet, Head of, N. Side
## 4      O  1507 Amai Inlet, S. Side, across from Soatwoon Cr.
## 5      O  1508                 Port Eliza (Beach 3)
## 6      O  1509                      Darr Island
##       Location TypeOfSample Year TotalArea Strata StrataNum StrataArea
## 1 Klaskino Inlet       StTS 2010       6150      1      1750
## 2 Klaskino Inlet       StTS 2010       6150      2      2400
## 3 Klaskino Inlet       StTS 2010       6150      3      2000
## 4    Amai Inlet       StTS 2010       2000      1      2000
## 5  Eliza Beach 3       StTS 2010       1200      1      1200
```

```
## 6   Darr Island      StTS 2010         125      1      125
##   SizeQuadrats
## 1         0.25
## 2         0.25
## 3         0.25
## 4         0.25
## 5         0.25
## 6         0.25
```

```
name.strat$Surveyname1 = paste("key",name.strat$H1_Key, name.strat$Location, n
ame.strat$Year,  "Stratum", name.strat$StrataNum,  sep = " ")

oyster2 <- read.csv("allkeyloc.csv", header=TRUE)
oyster2[is.na(oyster2)] <- 0

# subset to just STTS type of survey
oyster1 <- subset(oyster2, oyster2$TypeOfSample == "StTS", drop = TRUE)

# subset to just species 69H
oyster <- subset(oyster1, oyster1$Species == "69H", drop = TRUE)
rm(oyster1)
rm(oyster2)
#####BElow is where you change the counts for large or small or both
oyster$totalq <-  oyster$NumLegals +  oyster$NumSubLegals # use to use both size
oyster$total <- oyster$totalq * (1 / oyster$SqArea)

#oyster$total <-  oyster$NumLegals                #use this to get large only
#oyster$total <-  oyster$NumSubLegals              # use to get small only


oyster[1:5,]
```

```
##   Source BeachCode                        Location H1_Key
## 1    O 25-12-005 Port Eliza beach 3 2009 not index survey   1548
## 2    O 24-13-004                        Bacchante   1558
## 3    O 24-13-004                        Bacchante   1558
## 4    O 24-13-004                        Bacchante   1558
## 5    O 24-13-004                        Bacchante   1558
##          Description TypeOfSample Year MonthStart DayStart Stratum FSU
## 1 Port Eliza (Beach 3)       StTS 2009       8      5     1   4
## 2       Bacchante Bay       StTS 2015       7     15     3   8
## 3       Bacchante Bay       StTS 2015       7     15     3   8
## 4       Bacchante Bay       StTS 2015       7     15     3   9
## 5       Bacchante Bay       StTS 2015       7     15     3   9
##   SqArea QuadratNum Species NumLegals NumSubLegals totalq total
## 1 0.0625       19    69H       5          0     5   80
```

```
## 2 0.2500     74   69H     0       0   0   0
## 3 0.2500     59   69H     0       0   0   0
## 4 0.2500    104    69H     0       0   0   0
## 5 0.2500     98   69H     0       0   0   0
```

```
#makes a unique name for each stratum of each survey to be analyzed sepreatly
oyster$Surveyname = paste("key",oyster$H1_Key, oyster$Location, oyster$Year, "S
tratum", oyster$Stratum, sep = " ")
#unique(oyster$Surveyname)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
oysterp <- ddply(oyster, c("Surveyname","FSU"), summarise,
          Location = unique(Location),
          H1_Key = max(H1_Key),
          Year = max(Year),
          Stratum = max(Stratum),
          QuadratNum   = length(QuadratNum),
          total = sum(total),
          SqArea = max(SqArea),
          Diff = QuadratNum-total,
          SqAream2 = (1/SqArea),
          totalm2 = total*SqAream2)

#below us used to weight each transect in teh linear model
oysterp$weight <- 1/oysterp$QuadratNum
oysterp[1:5,]
```

```
##                  Surveyname FSU      Location H1_Key Year
## 1 key 1506 Klaskino Inlet 2010 Stratum 1   1 Klaskino Inlet   1506 2010
## 2 key 1506 Klaskino Inlet 2010 Stratum 1   2 Klaskino Inlet   1506 2010
## 3 key 1506 Klaskino Inlet 2010 Stratum 1   3 Klaskino Inlet   1506 2010
## 4 key 1506 Klaskino Inlet 2010 Stratum 1   4 Klaskino Inlet   1506 2010
## 5 key 1506 Klaskino Inlet 2010 Stratum 1   5 Klaskino Inlet   1506 2010
##  Stratum QuadratNum total SqArea Diff SqAream2 totalm2   weight
## 1     1         3     8   0.25   -5       4      32 0.3333333
## 2     1         3     0   0.25    3       4       0 0.3333333
## 3     1         3     0   0.25    3       4       0 0.3333333
## 4     1         3     0   0.25    3       4       0 0.3333333
## 5     1         3     0   0.25    3       4       0 0.3333333
```

```
################################

#Loop

# Get unique names
uNames <- unique( name.strat$Surveyname1 )
```

```
# Results - set up a table to store things
res <- data.frame( name=uNames,
            density=rep(NA, times=length(uNames)),
            stdErr=rep(NA, times=length(uNames)),
            SqArea=rep(NA, times=length(uNames)),
            #density.numby1meter=rep(NA, times=length(uNames)),
            #StdErrbymeter =rep(NA, times=length(uNames)),
            #quadnum =rep(NA, times=length(uNames)),
            Location =rep(NA, times=length(uNames)),
            Key=rep(NA, times=length(uNames)),
            Year=rep(NA, times=length(uNames)),
            Stratum=rep(NA, times=length(uNames)),
            SqArea.m2=rep(NA, times=length(uNames)),
            totalarea.m2=rep(NA, times=length(uNames)),
            StrataArea.m2=rep(NA, times=length(uNames)),
            #totalarea.quadsize=rep(NA, times=length(uNames)),
            #StrataArea.quadsize=rep(NA, times=length(uNames)),
            #pop.mean =rep(NA, times=length(uNames)),
            #pop.se =rep(NA, times=length(uNames)),
            #prop.area=rep(NA, times=length(uNames)),
            pop.est=rep(NA, times=length(uNames)),
            pop.est.se=rep(NA, times=length(uNames)),
            ratio.density=rep(NA, times=length(uNames)),
            ratio.var=rep(NA, times=length(uNames)),
            ratio.se=rep(NA, times=length(uNames)),
            ratio.ci=rep(NA, times=length(uNames)),
            Precision = NA,
            VybarSTS = NA)

# Start loop over names
for( i in 1:length(uNames) ) {
 # Get the ith name
 iName <- as.character( uNames[i] )

 # Get subset of oyster data for name i
 oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
 # Run the lm
 oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
 summary(oyster.fit)
 # Get lm coef
 res$density [i] <- coef( oyster.fit )[1]
 # Get std error of the estimate
res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]

itotalarea<- (name.strat$TotalAreaStrata [i])
```

```
 istrataArea<- (name.strat$StrataArea [i])
 temp <- as.character(oysterSub$Location)
# ilocation <- unique(temp)
# ilocation <- as.character(ilocation1)

 res$Location[i]<- unique(temp)
 res$Key[i]<- unique(oysterSub$H1_Key )
 res$Year [i] <- unique(oysterSub$Year )
 res$Stratum [i]  <- unique(oysterSub$Stratum )
 res$SqArea [i]  <- unique(oysterSub$SqArea )
 res$SqArea.m2 [i] <- unique(oysterSub$SqAream2)
 res$StrataArea.m2 [i]<- istrataArea
 res$totalarea.m2 [i] <- itotalarea
 res$Trannum [i] <- length(oysterSub$QuadratNum)
 res$quadcount [i] <- sum(oysterSub$QuadratNum)

 ##iStrataArea.quadsizecalculated <-  (name.strat$StrataArea [i]) * (unique(oysterS
ub$SqAream2)) This line was wrong

 oyster.design <- svydesign(data=oysterSub,
                  ids=~FSU,# clusters
                  variables=~total+QuadratNum,replace=T)

#print(oyster.design)

 est.ratio <- svyratio(numerator=~total,
               denominator=~QuadratNum,oyster.design)

est.ratio.ci <- confint(est.ratio)
est.ratio
est.ratio.ci

pop <- predict(est.ratio, total=istrataArea) # estimate total based on ratio
pop

 #pop <- predict(est.ratio, total=iStrataArea.quadsizecalculated ) # estimate total base
d on ratio
 res$pop.est [i] <- pop$total  #this takes the total from the ratio estimate puts in dataf
rame
 res$pop.est.se [i]<- pop$se   #this takes the se from the ratio estimate puts in datafra
me

 res$ratio.density [i] <-as.numeric (est.ratio [1])
 res$ratio.var [i] <- as.numeric(est.ratio [2])
 }
```

```
## Warning in svydesign.default(data = oysterSub, ids = ~FSU, variables =
## ~total + : No weights or probabilities supplied, assuming equal probability

 res$ratio.se <- sqrt(res$ratio.var)
 res$ratio.ci <- sqrt(res$ratio.var)*1.96
 res$CI95 <- sqrt(res$ratio.var)*1.96
############################################################

 #brings in data
# data <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-10-03.csv", h
eader=TRUE)
# head (data)
 data <- res

 data["W"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled wi
th "NA"
 data$W <- data$StrataArea.m2 / data$totalarea.m2
 data2 <- data

 data2["Wy"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
 data2$Wy <- data2$W*data2$density
 data3 <- data2


 data3["W2"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
 data3$W2 <- data3$ratio.var*data3$W*data3$W

 rm(data)
 rm(data2)

 # this the R version of the pivot table it make a table that summarizes each stratum
 # of each survey by transect to get the total number of quadrats and oyster
 All <- ddply(data3, c("Location","Year"), summarise,
        name = NA,
        Year = unique(Year),
        Location = unique(Location),
        density = sum (Wy),
        VybarSTS = sum (W2),
        stdErr = sqrt(VybarSTS),
        CI95 = 1.96 * sqrt(VybarSTS),
        Precision = (CI95/ density),
        SqArea = "NA",
        Key = "NA",
```

```
        Stratum = "All",
        SqArea.m2 = "NA",
        totalarea.m2 = "NA",
        StrataArea.m2 = "NA",
        pop.est = "NA",
        pop.est.se = "NA",
        ratio.density = "NA",
        ratio.var = "NA",
        ratio.se = "NA",
        ratio.ci = "NA",
        Trannum = "NA",
        quadcount = "NA")

rm(data3)

res2 <- rbind(res,All)
#res2 <- merge(res,All, by="Location")

#################################################################

currentDate <- Sys.Date()
csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2_",currentDa
te,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysislegals",currentDate,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysissmalls",currentDate,".csv",sep="")

write.csv(res2, file=csvFileName,row.names=FALSE, na="")

#write.csv(oysterSub, "data.csv", row.names=FALSE)

############################

rm(list=ls(all=TRUE))
#################################################################
#LARGE Oly counts only ########################################

#brings in data
name.strat <- read.csv("allkeylocnames.csv", header=TRUE)
head (name.strat)

##   Source H1_Key                        Description
## 1      O  1506          Klaskino Inlet, Head of, N. Side
## 2      O  1506          Klaskino Inlet, Head of, N. Side
## 3      O  1506          Klaskino Inlet, Head of, N. Side
## 4      O  1507 Amai Inlet, S. Side, across from Soatwoon Cr.
## 5      O  1508                 Port Eliza (Beach 3)
```

```
## 6    O  1509                          Darr Island
##       Location TypeOfSample Year TotalAreaStrata StrataNum StrataArea
## 1 Klaskino Inlet       StTS 2010        6150      1     1750
## 2 Klaskino Inlet       StTS 2010        6150      2     2400
## 3 Klaskino Inlet       StTS 2010        6150      3     2000
## 4    Amai Inlet        StTS 2010        2000      1     2000
## 5  Eliza Beach 3       StTS 2010        1200      1     1200
## 6   Darr Island        StTS 2010         125      1      125
##  SizeQuadrats
## 1         0.25
## 2         0.25
## 3         0.25
## 4         0.25
## 5         0.25
## 6         0.25
```

```
name.strat$Surveyname1 = paste("key",name.strat$H1_Key, name.strat$Location, n
ame.strat$Year,  "Stratum", name.strat$StrataNum,  sep = " ")

oyster2 <- read.csv("allkeyloc.csv", header=TRUE)
oyster2[is.na(oyster2)] <- 0

# subset to just STTS type of survey
oyster1 <- subset(oyster2, oyster2$TypeOfSample == "StTS", drop = TRUE)

# subset to just species 69H
oyster <- subset(oyster1, oyster1$Species == "69H", drop = TRUE)
rm(oyster1)
rm(oyster2)
#####BElow is where you change the counts for large or small or both
#oyster$total <-  oyster$NumLegals +  oyster$NumSubLegals # use to use both size
oyster$totalq <-  oyster$NumLegals                #use this to get large only
oyster$total <- oyster$totalq * (1/ oyster$SqArea)
#oyster$total <-  oyster$NumSubLegals              # use to get small only

oyster[1:5,]
```

```
##  Source BeachCode                      Location H1_Key
## 1    O 25-12-005 Port Eliza beach 3 2009 not index survey   1548
## 2    O 24-13-004                       Bacchante   1558
## 3    O 24-13-004                       Bacchante   1558
## 4    O 24-13-004                       Bacchante   1558
## 5    O 24-13-004                       Bacchante   1558
##         Description TypeOfSample Year MonthStart DayStart Stratum FSU
## 1 Port Eliza (Beach 3)       StTS 2009       8      5     1  4
## 2      Bacchante Bay       StTS 2015       7     15     3  8
```

```
## 3      Bacchante Bay      StTS 2015      7     15     3  8
## 4      Bacchante Bay      StTS 2015      7     15     3  9
## 5      Bacchante Bay      StTS 2015      7     15     3  9
##   SqArea QuadratNum Species NumLegals NumSubLegals totalq total
## 1 0.0625       19    69H       5          0     5   80
## 2 0.2500       74    69H       0          0     0    0
## 3 0.2500       59    69H       0          0     0    0
## 4 0.2500      104    69H       0          0     0    0
## 5 0.2500       98    69H       0          0     0    0

#makes a unique name for each stratum of each survey to be analyzed sepreatly
oyster$Surveyname = paste("key",oyster$H1_Key, oyster$Location, oyster$Year,  "S
tratum", oyster$Stratum,  sep = " ")
#unique(oyster$Surveyname)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
oysterp <- ddply(oyster, c("Surveyname","FSU"), summarise,
          Location = unique(Location),
          H1_Key = max(H1_Key),
          Year = max(Year),
          Stratum = max(Stratum),
          QuadratNum    = length(QuadratNum),
          total = sum(total),
          SqArea = max(SqArea),
          Diff = QuadratNum-total,
          SqAream2 = (1/SqArea),
          totalm2 = total*SqAream2)

#below us used to weight each transect in teh linear model
oysterp$weight <- 1/oysterp$QuadratNum
#oysterp[1:5,]

################################

#Loop
# Get unique names
uNames <- unique( name.strat$Surveyname1 )

# Results - set up a table to store things
res <- data.frame( name=uNames,
          density=rep(NA, times=length(uNames)),
          stdErr=rep(NA, times=length(uNames)),
          SqArea=rep(NA, times=length(uNames)),
          #density.numby1meter=rep(NA, times=length(uNames)),
          #StdErrbymeter =rep(NA, times=length(uNames)),
```

```
                #quadnum =rep(NA, times=length(uNames)),
                Location =rep(NA, times=length(uNames)),
                Key=rep(NA, times=length(uNames)),
                Year=rep(NA, times=length(uNames)),
                Stratum=rep(NA, times=length(uNames)),
                SqArea.m2=rep(NA, times=length(uNames)),
                totalarea.m2=rep(NA, times=length(uNames)),
                StrataArea.m2=rep(NA, times=length(uNames)),
                #totalarea.quadsize=rep(NA, times=length(uNames)),
                #StrataArea.quadsize=rep(NA, times=length(uNames)),
                #pop.mean =rep(NA, times=length(uNames)),
                #pop.se =rep(NA, times=length(uNames)),
                #prop.area=rep(NA, times=length(uNames)),
                pop.est=rep(NA, times=length(uNames)),
                pop.est.se=rep(NA, times=length(uNames)),
                ratio.density=rep(NA, times=length(uNames)),
                ratio.var=rep(NA, times=length(uNames)),
                ratio.se=rep(NA, times=length(uNames)),
                ratio.ci=rep(NA, times=length(uNames)),
                Precision = NA,
                VybarSTS = NA)

# Start loop over names
for( i in 1:length(uNames) ) {
 # Get the ith name
 iName <- as.character( uNames[i] )

 # Get subset of oyster data for name i
 oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
 # Run the lm
 oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
 summary(oyster.fit)
 # Get lm coef
 res$density [i] <- coef( oyster.fit )[1]
 # Get std error of the estimate
 res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]

 itotalarea<- (name.strat$TotalAreaStrata [i])
 istrataArea<- (name.strat$StrataArea [i])
 temp <- as.character(oysterSub$Location)
 # ilocation <- unique(temp)
 # ilocation <- as.character(ilocation1)

 res$Location[i]<- unique(temp)
 res$Key[i]<- unique(oysterSub$H1_Key )
 res$Year [i] <- unique(oysterSub$Year )
```

```
  res$Stratum [i]  <- unique(oysterSub$Stratum )
  res$SqArea [i]  <- unique(oysterSub$SqArea )
  res$SqArea.m2 [i] <- unique(oysterSub$SqAream2)
  res$StrataArea.m2 [i]<- istrataArea
  res$totalarea.m2 [i] <- itotalarea
  res$Trannum [i] <- length(oysterSub$QuadratNum)
  res$quadcount [i] <- sum(oysterSub$QuadratNum)

  ##iStrataArea.quadsizecalculated <-  (name.strat$StrataArea [i]) * (unique(oysterS
ub$SqAream2)) This line was wrong

  oyster.design <- svydesign(data=oysterSub,
                  ids=~FSU,# clusters
                  variables=~total+QuadratNum,replace=T)

  #print(oyster.design)

  est.ratio <- svyratio(numerator=~total,
              denominator=~QuadratNum,oyster.design)

  est.ratio.ci <- confint(est.ratio)
  est.ratio
  est.ratio.ci

  pop <- predict(est.ratio, total=istrataArea) # estimate total based on ratio
  pop

  #pop <- predict(est.ratio, total=iStrataArea.quadsizecalculated ) # estimate total bas
ed on ratio
  res$pop.est [i] <- pop$total  #this takes the total from the ratio estimate puts in data
frame
  res$pop.est.se [i]<- pop$se   #this takes the se from the ratio estimate puts in datafra
me

  res$ratio.density [i] <-as.numeric (est.ratio [1])
  res$ratio.var [i] <- as.numeric(est.ratio [2])

}

## Warning in svydesign.default(data = oysterSub, ids = ~FSU, variables =
## ~total + : No weights or probabilities supplied, assuming equal probability

res$ratio.se <- sqrt(res$ratio.var)
res$ratio.ci <- sqrt(res$ratio.var)*1.96
res$CI95 <- sqrt(res$ratio.var)*1.96
#################################################################
```

```
#brings in data
# data <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-10-03.csv", h
eader=TRUE)
# head (data)
data <- res

data["W"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled wit
h "NA"
data$W <- data$StrataArea.m2 / data$totalarea.m2
data2 <- data

data2["Wy"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
data2$Wy <- data2$W*data2$density
data3 <- data2

data3["W2"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
data3$W2 <- data3$ratio.var*data3$W*data3$W

rm(data)
rm(data2)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
All <- ddply(data3, c("Location","Year"), summarise,
        name = NA,
        Year = unique(Year),
        Location = unique(Location),
        density = sum (Wy),
        VybarSTS = sum (W2),
        stdErr = sqrt(VybarSTS),
        CI95 = 1.96 * sqrt(VybarSTS),
        Precision = (CI95/ density),
        SqArea = "NA",
        Key = "NA",
        Stratum = "All",
        SqArea.m2 = "NA",
        totalarea.m2 = "NA",
        StrataArea.m2 = "NA",
        pop.est = "NA",
        pop.est.se = "NA",
        ratio.density = "NA",
        ratio.var = "NA",
        ratio.se = "NA",
```

```
        ratio.ci = "NA",
        Trannum = "NA",
        quadcount = "NA")


rm(data3)

res2 <- rbind(res,All)
#res2 <- merge(res,All, by="Location")

##################################################################

currentDate <- Sys.Date()
#csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2_",currentDate
,".csv",sep="")
csvFileName <- paste("Olyclusteranalysislegals",currentDate,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysissmalls",currentDate,".csv",sep="")

write.csv(res2, file=csvFileName,row.names=FALSE, na="")

#write.csv(oysterSub, "data.csv", row.names=FALSE)

#########################

rm(list=ls(all=TRUE))
##################################################################
#Small Oly counts only  ########################################

#brings in data
name.strat <- read.csv("allkeylocnames.csv", header=TRUE)
head (name.strat)

##  Source H1_Key                        Description
## 1      O  1506          Klaskino Inlet, Head of, N. Side
## 2      O  1506          Klaskino Inlet, Head of, N. Side
## 3      O  1506          Klaskino Inlet, Head of, N. Side
## 4      O  1507 Amai Inlet, S. Side, across from Soatwoon Cr.
## 5      O  1508                  Port Eliza (Beach 3)
## 6      O  1509                       Darr Island
##       Location TypeOfSample Year TotalArea Strata StrataNum StrataArea
## 1 Klaskino Inlet       StTS 2010       6150      1      1750
## 2 Klaskino Inlet       StTS 2010       6150      2      2400
## 3 Klaskino Inlet       StTS 2010       6150      3      2000
## 4    Amai Inlet       StTS 2010       2000      1      2000
## 5  Eliza Beach 3       StTS 2010       1200      1      1200
## 6   Darr Island       StTS 2010        125      1       125
```

```
##   SizeQuadrats
## 1         0.25
## 2         0.25
## 3         0.25
## 4         0.25
## 5         0.25
## 6         0.25
```

```
name.strat$Surveyname1 = paste("key",name.strat$H1_Key, name.strat$Location, n
ame.strat$Year,  "Stratum", name.strat$StrataNum,  sep = " ")

oyster2 <- read.csv("allkeyloc.csv", header=TRUE)
oyster2[is.na(oyster2)] <- 0

# subset to just STTS type of survey
oyster1 <- subset(oyster2, oyster2$TypeOfSample == "StTS", drop = TRUE)

# subset to just species 69H
oyster <- subset(oyster1, oyster1$Species == "69H", drop = TRUE)
rm(oyster1)
rm(oyster2)
#####BElow is where you change the counts for large or small or both
#oyster$total <-  oyster$NumLegals +  oyster$NumSubLegals # use to use both size
#oyster$total <-  oyster$NumLegals                  #use this to get large only
oyster$totalq <-  oyster$NumSubLegals               # use to get small only
oyster$total <- oyster$totalq * (1/ oyster$SqArea)

oyster[1:5,]
```

```
##   Source BeachCode                        Location H1_Key
## 1    O 25-12-005 Port Eliza beach 3 2009 not index survey   1548
## 2    O 24-13-004                          Bacchante   1558
## 3    O 24-13-004                          Bacchante   1558
## 4    O 24-13-004                          Bacchante   1558
## 5    O 24-13-004                          Bacchante   1558
##          Description TypeOfSample Year MonthStart DayStart Stratum FSU
## 1 Port Eliza (Beach 3)       StTS 2009        8        5       1  4
## 2       Bacchante Bay       StTS 2015        7       15       3  8
## 3       Bacchante Bay       StTS 2015        7       15       3  8
## 4       Bacchante Bay       StTS 2015        7       15       3  9
## 5       Bacchante Bay       StTS 2015        7       15       3  9
##   SqArea QuadratNum Species NumLegals NumSubLegals totalq total
## 1 0.0625        19    69H        5          0      0     0
## 2 0.2500        74    69H        0          0      0     0
## 3 0.2500        59    69H        0          0      0     0
```

```
## 4 0.2500      104    69H      0        0    0    0
## 5 0.2500       98    69H      0        0    0    0

#makes a unique name for each stratum of each survey to be analyzed sepreatly
oyster$Surveyname = paste("key",oyster$H1_Key, oyster$Location, oyster$Year,  "S
tratum", oyster$Stratum,  sep = " ")
#unique(oyster$Surveyname)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
oysterp <- ddply(oyster, c("Surveyname","FSU"), summarise,
          Location = unique(Location),
          H1_Key = max(H1_Key),
          Year = max(Year),
          Stratum = max(Stratum),
          QuadratNum    = length(QuadratNum),
          total = sum(total),
          SqArea = max(SqArea),
          Diff = QuadratNum-total,
          SqAream2 = (1/SqArea),
          totalm2 = total*SqAream2)


#below us used to weight each transect in teh linear model
oysterp$weight <- 1/oysterp$QuadratNum
#oysterp[1:5,]

################################

#Loop

# Get unique names
uNames <- unique( name.strat$Surveyname1 )

# Results - set up a table to store things
res <- data.frame( name=uNames,
          density=rep(NA, times=length(uNames)),
          stdErr=rep(NA, times=length(uNames)),
          SqArea=rep(NA, times=length(uNames)),
          #density.numby1meter=rep(NA, times=length(uNames)),
          #StdErrbymeter =rep(NA, times=length(uNames)),
          #quadnum =rep(NA, times=length(uNames)),
          Location =rep(NA, times=length(uNames)),
          Key=rep(NA, times=length(uNames)),
          Year=rep(NA, times=length(uNames)),
          Stratum=rep(NA, times=length(uNames)),
```

```
    SqArea.m2=rep(NA, times=length(uNames)),
    totalarea.m2=rep(NA, times=length(uNames)),
    StrataArea.m2=rep(NA, times=length(uNames)),
    #totalarea.quadsize=rep(NA, times=length(uNames)),
    #StrataArea.quadsize=rep(NA, times=length(uNames)),
    #pop.mean =rep(NA, times=length(uNames)),
    #pop.se =rep(NA, times=length(uNames)),
    #prop.area=rep(NA, times=length(uNames)),
    pop.est=rep(NA, times=length(uNames)),
    pop.est.se=rep(NA, times=length(uNames)),
    ratio.density=rep(NA, times=length(uNames)),
    ratio.var=rep(NA, times=length(uNames)),
    ratio.se=rep(NA, times=length(uNames)),
    ratio.ci=rep(NA, times=length(uNames)),
    Precision = NA,
    VybarSTS = NA)

# Start loop over names
for( i in 1:length(uNames) ) {
 # Get the ith name
 iName <- as.character( uNames[i] )

 # Get subset of oyster data for name i
 oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
 # Run the lm
 oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
 summary(oyster.fit)
 # Get lm coef
 res$density [i] <- coef( oyster.fit )[1]
 # Get std error of the estimate
 res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]

 itotalarea<- (name.strat$TotalAreaStrata [i])
 istrataArea<- (name.strat$StrataArea [i])
 temp <- as.character(oysterSub$Location)
 # ilocation <- unique(temp)
 # ilocation <- as.character(ilocation1)

 res$Location[i]<- unique(temp)
 res$Key[i]<- unique(oysterSub$H1_Key )
 res$Year [i] <- unique(oysterSub$Year )
 res$Stratum [i]  <- unique(oysterSub$Stratum )
 res$SqArea [i]  <- unique(oysterSub$SqArea )
 res$SqArea.m2 [i] <- unique(oysterSub$SqAream2)
 res$StrataArea.m2 [i]<- istrataArea
 res$totalarea.m2 [i] <- itotalarea
```

```
 res$Trannum [i] <- length(oysterSub$QuadratNum)
 res$quadcount [i] <- sum(oysterSub$QuadratNum)


 ##iStrataArea.quadsizecalculated <-  (name.strat$StrataArea [i]) * (unique(oysterS
ub$SqAream2)) This line was wrong

 oyster.design <- svydesign(data=oysterSub,
                  ids=~FSU,# clusters
                  variables=~total+QuadratNum,replace=T)

 #print(oyster.design)

 est.ratio <- svyratio(numerator=~total,
               denominator=~QuadratNum,oyster.design)

 est.ratio.ci <- confint(est.ratio)
 est.ratio
 est.ratio.ci

 pop <- predict(est.ratio, total=istrataArea) # estimate total based on ratio
 pop

 #pop <- predict(est.ratio, total=iStrataArea.quadsizecalculated ) # estimate total bas
ed on ratio
 res$pop.est [i] <- pop$total  #this takes the total from the ratio estimate puts in data
frame
 res$pop.est.se [i]<- pop$se   #this takes the se from the ratio estimate puts in datafra
me

 res$ratio.density [i] <-as.numeric (est.ratio [1])
 res$ratio.var [i] <- as.numeric(est.ratio [2])

}

## Warning in svydesign.default(data = oysterSub, ids = ~FSU, variables =
## ~total + : No weights or probabilities supplied, assuming equal probability

res$ratio.se <- sqrt(res$ratio.var)
res$ratio.ci <- sqrt(res$ratio.var)*1.96
res$CI95 <- sqrt(res$ratio.var)*1.96
#############################################################

#brings in data
# data <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-10-03.csv", h
eader=TRUE)
```

```
# head (data)
data <- res

data["W"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled wit
h "NA"
data$W <- data$StrataArea.m2 / data$totalarea.m2
data2 <- data

data2["Wy"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
data2$Wy <- data2$W*data2$density
data3 <- data2

data3["W2"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
data3$W2 <- data3$ratio.var*data3$W*data3$W

rm(data)
rm(data2)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
All <- ddply(data3, c("Location","Year"), summarise,
        name = NA,
        Year = unique(Year),
        Location = unique(Location),
        density = sum (Wy),
        VybarSTS = sum (W2),
        stdErr = sqrt(VybarSTS),
        CI95 = 1.96 * sqrt(VybarSTS),
        Precision = (CI95/ density),
        SqArea = "NA",
        Key = "NA",
        Stratum = "All",
        SqArea.m2 = "NA",
        totalarea.m2 = "NA",
        StrataArea.m2 = "NA",
        pop.est = "NA",
        pop.est.se = "NA",
        ratio.density = "NA",
        ratio.var = "NA",
        ratio.se = "NA",
        ratio.ci = "NA",
        Trannum = "NA",
        quadcount = "NA")
```

```
rm(data3)

res2 <- rbind(res,All)
#res2 <- merge(res,All, by="Location")


#################################################################

currentDate <- Sys.Date()
#csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2_",currentDate
,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysislegals",currentDate,".csv",sep="")
csvFileName <- paste("Olyclusteranalysissmalls",currentDate,".csv",sep="")

write.csv(res2, file=csvFileName,row.names=FALSE, na="")

#write.csv(oysterSub, "data.csv", row.names=FALSE)
```

**Appendix 2. R code used for calculating density of Olympia oysters at each site in 3 different size category formats ("Only small oysters (≤15mm)", "Large (>15mm) and small oysters (≤15mm)", and "Large oysters (>15mm) only").**

## DensityGraphsLoopFinal17Oct03.R

BiggM

Wed Dec 13 17:16:05 2017
################## Olympia Oyster Density Graphs ##################

```
# Author:       Tammy Norgard and Jessica Finney
# Affiliation:  Pacific Biological Station, Fisheries and Oceans Canada (DFO)
# Group:        Shellfish, Marine Ecosystems and Aquaculture Division
# Address:      3190 Hammond Bay Road, Nanaimo, BC, Canada, V9T 6N7
# Contact:      e-mail: jessica.finney@dfo-mpo.gc.ca | tel: 250.756.7023
# Project:      Olympia oysters
# Code name:    DensityGraphsLoop.R
# Version:      1.0
# Date started: Nov 2, 2015
# Date edited:

# Overview:
# Plots density estimates by beach, year and strata with error bard

# Requirements: Olympia oyster data on density in each strata for each location

#################################################################

# Clear workspace
rm(list=ls(all=TRUE))
while("data.sub" %in% search()) detach(data.sub)   #if script has previsously
crashed, data.sub will still be attached.

# Load packages
#install.packages("ggplot2")
library(ggplot2)
```

## Warning: package 'ggplot2' was built under R version 3.2.5

```
library(dplyr)
```

## Warning: package 'dplyr' was built under R version 3.2.5

```
##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##
##    filter, lag

## The following objects are masked from 'package:base':
##
##    intersect, setdiff, setequal, union

#######################################
# Read in data
#######################################

# Read in data for legal, legal and Small, and small only

# Legal and small
LegSmOyster <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-11
-23.csv",
                header=TRUE, as.is=TRUE, strip.white=TRUE)

# Small only
SmOyster <- read.csv("Olyclusteranalysissmalls2017-11-23.csv",
              header=TRUE, as.is=TRUE, strip.white=TRUE)

#######################################
# Merge datasets
#######################################

# Add Size column to each data frame
LegSmOyster <- mutate(LegSmOyster, Size = "All sizes")
SmOyster    <- mutate(SmOyster, Size = "Small")

# Merge
OysterDat <- rbind(LegSmOyster, SmOyster)

#######################################
# Get unique locations
#######################################

OysterLocations <- unique(OysterDat$Location)

#######################################
# Function for plotting density
#######################################
```

```
# Note: the directory parameter must be in brackets,
# e.g. "Results-Legal", "Results-Legal and Small", or "Results-Small"

PlotDensity <- function(locations, dendata, directory) {

 for ( i in 1:length(locations) ) {

  # Subset data to specific location
  plot_data       <- subset(dendata, Location == locations[i])

  # Make year and stratum into factors for easier plotting
  plot_data$Year   <- as.factor(plot_data$Year)
  #plot_data$Stratum <-as.factor(plot_data$Stratum)

  # Create directory for plots to be saved
  mainDir<-getwd()
  subDir<- directory # folder name
  dir.create(file.path(mainDir, subDir), showWarnings = FALSE)
  results.dir<-file.path(mainDir, subDir)

  # Create file name for saved plot
  currentDate <- Sys.Date()
  jpegFileName <- paste(locations[i],currentDate, ".jpeg",sep="")

  # Set error bar limits
  #limits <- aes(ymax = density.numbyqsize + 2*stdErr, ymin=max((density.numbyqsiz
e - 2*stdErr), 0))

  limits <- aes(ymax = density + 2*stdErr, ymin= ifelse((density - 2*stdErr)<0, 0, (d
ensity - 2*stdErr) ))

  # Because the bars and errorbars have different widths
  # we need to specify how wide the objects we are dodging are
  dodge <- position_dodge(width=0.9)

  # Plot density in each stratum
  plot <- ggplot(plot_data, aes(fill=Stratum, y=density, x=Year)) +
   facet_grid(.~Size) +
   geom_bar(position="dodge", stat="identity") +
   scale_fill_grey(start = 0.3, end = 0.8) +
   geom_errorbar(limits, position=dodge, width=0.25) +
   ylab(bquote(.("Density" ~ "(Oysters/m"^2 ~ ")" ))) +
   theme_bw() +
   theme(panel.grid.minor.x=element_blank(),
       panel.grid.major.x=element_blank(),
       strip.text.x = element_text(size = 24),
```

```
        axis.title=element_text(size=16),
        axis.text=element_text(size=12))
    ggsave(filename= paste(results.dir, jpegFileName, sep = "/"))

  } # End location for loop

} # End PlotDensity function


#######################################
# Run function
#######################################

PlotDensity(locations = OysterLocations, dendata = OysterDat, directory = "All")
```

**Appendix 3. R code for Olympia oyster density graphs**

## LengthFrequencyDist_JFedits.r

BiggM

Wed Dec 13 17:18:18 2017

```
########## Initial cleanup ##########
rm(list=ls(all=TRUE))
# Code to make length frequency histograms of Olympia oyster index site bio samples

# Written by:    Jessica Finney
# Last modified:  May 11, 2016


# This code requires an input table from Access that can be obtained using the XXXXX
query in the Clams database.  Use the query to select the locations and years you want.

# Load packages
#install.packages(c("moments", "plotrix", "dplyr"))
library(plyr)

## Warning: package 'plyr' was built under R version 3.2.5

library(moments)

## Warning: package 'moments' was built under R version 3.2.5

library(plotrix)
library(dplyr)

## Warning: package 'dplyr' was built under R version 3.2.5

##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:plyr':
##
##    arrange, count, desc, failwith, id, mutate, rename, summarise,
##    summarize

## The following objects are masked from 'package:stats':
##
##    filter, lag
```

```
## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union

library(ggplot2)

## Warning: package 'ggplot2' was built under R version 3.2.5

# Read in table from Access
# file name from the Access XXX quer
dat <- read.csv("qselBioSamplesTable.csv", header=TRUE)

# Remove columns with NA in length
dat <- dat %>%
 filter(!is.na(Length))

# Calculate maximum and minimum lengths (for plotting purposes)
LengthMax = max(dat$Length, na.rm=T)
LengthMin = min(dat$Length, na.rm =T)

#### Divide into locations and plot as histograms

# Create a list of the unique locations in the dat table
locations = unique (dat$Location)

# Group data by location and year
groupdat <- dat%>%
 group_by(Location, Year)

# Calculate statistics for each location and year grouping
biostats  <- summarise(groupdat, n = n(), Mean=mean(Length), SE = std.error(Len
gth),
            Median = median(Length), Kurtosis = kurtosis(Length), Skewness = ske
wness(Length),
            Min = min(Length), Max = max(Length), Range = max(Length)-min(Len
gth))
biostats  <- as.data.frame(biostats)

# Make text file of biostats table
write.table(biostats, file = "Biostats.txt", row.names = FALSE, col.names = TRUE, se
p = ",")
write.table(biostats, file = "Biostats.csv", row.names = FALSE, col.names = TRUE, se
p = ",")

# For loop to plot length frequency graphs for each beach and year
for( i in 1:length(locations) ) {
```

```
  # Subset data from beach i
  beachi <- locations[i]
  beachdat <- dat%>%
   filter(Location == beachi )

  beachmean <- biostats %>%
   filter(Location == beachi)

  # Set label location
  xloc <- 0.9 * max(beachdat$Length) # 80% of maximum length value
  ydat <- ddply(beachdat, .(Length, Year), summarise, Freq = length(Length))
  yloc <- 0.8 * max(ydat$Freq)


  locplot <- ggplot(beachdat, aes(Length)) +
   theme_bw( ) +
   facet_grid(Year~.) +
   #opts(strip.text.y = theme_text(size = 8)) +
   theme(strip.text.y = element_text(size = 24),
       axis.text = element_text(size = 12),
       axis.title=element_text(size=16)) +
   geom_bar() +
   geom_vline(aes(xintercept = Mean), data = beachmean, linetype = "longdash", col
our = "red") +
   geom_text(data = beachmean, inherit.aes = FALSE, size = 8,
         aes(label = paste("n = ", n, sep = "")), x = xloc, y = yloc) +
   scale_x_continuous(breaks = seq(from = 0, to = max(beachdat$Length), by = 5))
+
   xlim(0,65)+
   #5g scale_x_continuous(, by = 5)) +
   labs( x="Length (mm)", y="Number of oysters" )
  ggsave( file= paste(locations[i], "jpg", sep = "." ))

  } # Close locations loop
```